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Water Resources Management Plan

BANDELIER

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Acronyms and Abbreviations

BRD	Biological Resources Division
cfs	cubic feet per second
ERW	Extraordinary Resource Water
ET	Evapotranspiration
IBWG	Interagency Biological Working Group
LANL	Los Alamos National Laboratory
MOU	Memorandum of Understanding
MRGCD	Middle Rio Grande Conservation District
NAWQA	National Ambient Water Quality Assessment Program
NMED	New Mexico Environmental Department
NMGF	New Mexico Game and Fish
NPS	National Park Service
ONRW	Outstanding Natural Resource Waters
TDS	Total Dissolved Solids
USACE	United States Army Corps of Engineers
USDE	United States Department of Energy
USDI	United States Department of Interior
USFS	United States Forest Service
USGS	United States Geological Survey
WRMP	Water Resources Management Plan

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WATER RESOURCES MANAGEMENT PLAN

BANDELIER NATIONAL MONUMENT
New Mexico

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November 1999

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EXECUTIVE SUMMARY

Water Resources Management Plans (WRMP) provide National Park Service (NPS) managers a technical summary of water resources, issue analysis, and recommendations for future actions and studies. This Plan describes hydrologic and related physical processes within northern New Mexico's Bandelier National Monument. While initially established as a cultural unit of the national park system, Bandelier also contains significant ground and surface water resources, including alluvial, perched, and main aquifer ground water, springs, perennial streams, flood plains, riparian zones, and wetlands. The Monument's hydrologic environment is closely linked to its anthropogenic setting and biological resources, and water resources are discussed in this context.

Most of Bandelier's watersheds drain U.S. Forest Service or private lands before entering the Monument and have been impacted by activities and management practices on these external lands. The neighboring Los Alamos National Laboratory has a significant legacy of environmental contamination, some of which could potentially migrate to Bandelier via ground water transport. The downstream Cochiti Dam seasonally inundates the Rio Grande riparian zone and has dramatically altered this unique portion of the Monument's environment. Internal management practices ranging from fire suppression to infrastructure development have been particularly detrimental to aquatic habitats.

A highlight of the specific issues and developed recommendations discussed in this Plan includes:

1) Watershed Management - Past fire and vegetation management at the watershed scale ultimately resulted in widespread, intense, wildfires. The flooding and sediment delivery that ensued exceeded the assimilative capacity of Monument streams and aquatic habitat and communities were degraded. Two components of watershed management were recognized as critical to maintaining natural stream condition and function:

1a) Fire Management
Nearly a century of fire suppression at Bandelier resulted in unnatural plant communities and fuel loading. Intense wildfires in 1977 and 1996 brought about repeated floods and widespread degradation of stream habitat, aquatic communities, and riparian vegetation.

Recommendation
Watershed function should be maintained through restoration of natural vegetative communities and associated fire regimes. Prescribed fire and vegetative restoration techniques should be implemented. Specific studies should be employed to assess the relationship between prescribed fire and hydrology.

1b) Erosion Management
Elevated rates of watershed erosion are delivering excess sediment to Bandelier's streams, especially during post-fire conditions. Excess sediment negatively impacts streams by decreasing habitat diversity, covering spawning areas, increasing turbidity, and other factors that ultimately reduce biological diversity.

Recommendation
Efforts to mitigate erosion through restoration of plant communities should continue. Additionally, roads and trails within the watersheds should be examined to determine if they can be closed and renovated, or if improved drainage attributes can be installed. Streambank erosion and riparian impacts should also be mitigated through restoration and continued monitoring and evaluation of ungulate populations.

2) Infrastructure - Development and promotion of visitor access in discrete areas has the potential to degrade the resources the National Park Service was mandated to protect. Intensive visitor access and concomitant sewage, hazardous waste, and flood plain issues characterize the heavily developed reach of Frijoles Canyon near Monument headquarters.

2a) Visitor Access
Unconstrained social usage near Cottonwood Picnic Area has resulted in the trampling of Frijoles Creek's stream banks and channel. Tramping has produced stream banks devoid of vegetation, an overwidened stream channel, decreased sediment size, and increased embeddedness. Changes in these physical attributes cause reduced habitat quality.

Recommendation
Visitor access should be restricted within the degraded reach and native vegetation reestablished on stream banks and riparian areas. Natural recovery processes will allow the headquarters reach to regain pre-disturbance channel dimensions and habitat attributes.

2b) Sewage and Hazardous Waste
Water quality monitoring has indicated that sewage is possibly leaching into Frijoles Creek from the headquarters sewage system. Direct spills of sewage from the lift station to this stream have been observed in the past. The proximity of maintenance facilities, housing, concessions operations, and management offices to Frijoles Creek also highlights the need for competent management of hazardous materials stored or utilized in these areas.

Recommendation
The sewage lift station should be replaced or retrofitted to alleviate problems that result in spillage of raw sewage. Assessment of potential leakage from sewage pipes should also be initiated. The Monument's Hazardous Materials Plan should be strictly enforced.

2c) Flood Plain Management
Some of the headquarters infrastructure is within Frijoles Canyon's mapped 100-year flood plain and has been flooded in the past. In historic times, large magnitude floods have only been documented during post-fire periods. Overbank flooding can occur due to logjams, and geomorphic indicators suggest potentially devastating floods have occurred in the geologic past.

Recommendation
A qualified geomorphologist should be retained to assess the possibility of overflow or outbreak flooding impacting Monument headquarters or Base Camp. Restoration of natural fire regimes is also critical to prevent flooding. Bandelier should remove debris jams that might reroute high flows out of stream channels only when there is a clear threat to life or property.

3) Fish Management
Area fisheries biologists believe the regionally native Rio Grande cutthroat trout was endemic to Frijoles and Capulin creeks. Past stocking with exotic salmonids would have eliminated native cutthroat and could be altering other elements of aquatic communities (e.g. macroinvertebrates). Monument managers are concerned that chemical extermination of exotic fish would affect other stream organisms, and that unauthorized restocking by a disgruntled angler might jeopardize restoration efforts.

Recommendation
New techniques implemented in, for example, Great Smoky Mountains National Park utilize multi-pass electroshocking runs to remove exotic fish species from appropriate stream reaches. Bandelier managers should discuss this elimination alternative with New Mexico Department of Game and Fish and U.S. Fish and Wildlife Service biologists to determine if multi-pass electroshocking would be feasible in Frijoles Creek to remove exotics without the use of toxins.

4) Los Alamos National Laboratory (LANL) - Radioactive and hazardous waste disposal practices over the past five decades have resulted in significant ground water, sediment, and atmospheric contamination:

4a) Ground Water
Extensive ground water contamination has been documented in all three ground water zones below LANL. Of particular concern to Bandelier is contamination of perched ground water. Recent hydro-stratigraphic mapping and interpretation indicate perched water could be migrating toward Bandelier and recharging Frijoles or Alamo Canyons. Perched water and associated contaminants could also be migrating through the Pajarito Fault zone.

Recommendation
LANL should install ground water monitoring wells to assess the potential for contaminant migration into Bandelier's surface waters. A series of seepage runs should be performed on Frijoles Creek and Alamo Canyon, to determine reaches characterized by ground water recharge. Shallow wells should also be located within the alluvial sediments of Frijoles Canyon to characterize ground water movement and potential contaminant attributes within this system.

4b) Sediments
Natural stream processes have transported radionuclide-contaminated sediments from LANL canyons to Bandelier lands within the backwaters of Cochiti Reservoir.

Recommendation
Bandelier staff should consult with the New Mexico Department of Environmental Quality to determine if radioactive sediment poses a concern for Monument staff, visitors, or biological resources.

4c) Atmospheric Transport
Atmospheric releases of hazardous and radioactive contaminants from LANL have occurred and are ongoing. Perimeter sampling has not indicated problems and current releases are reported to be low.

Recommendation
Bandelier should rely on LANL's and the New Mexico Department of Environmental Quality's atmospheric compliance and monitoring to protect Monument visitors and resources.

5) Cochiti Reservoir
Cochiti Reservoir seasonally inundates up to 350 acres of Monument lands. Recreational pool adjustments to compensate for sedimentation are resulting in permanent flooding of the Rio Grande corridor. While resource damage has been extensive, a wetland environment is emerging within the delta, offsetting regional wetland losses and providing critical habitat along the Rio Grande flyway.

Recommendation
Bandelier should continue their efforts to mitigate Cochiti related impacts and block attempts to change reservoir operations to the further detriment of natural resources. Bandelier should also participate in the U.S Army Corps of Engineers' suggestion to scope out the best way to meet all of Cochiti's mandates, now and in the future.

6) DDT
In the 1950s and 1960s, Bandelier used DDT and other chlorinated hydrocarbons to control "pests" near Monument headquarters. In 1975, the State of New Mexico discovered high levels of DDT contaminants in Frijoles Creek and subsequent studies showed high concentrations in sediment and fish tissue. A ban was placed on fish consumption and remedial investigations and clean-up have been implemented.

Recommendation
Bandelier should develop a plan in conjunction with the New Mexico Game and Fish Department and the New Mexico Department of Environmental Quality to determine if the fishing ban can be lifted.

7) External Impacts Within Upper Watersheds

Excluding the Frijoles basin, all of Bandelier's upper watersheds are under U.S. Forest Service or private ownership. Multiple use management and private development have impacted downstream water resources within Bandelier. A recent U.S. Forest Service proposal would designate part of the headwaters as a grass bank for future intensive cattle stocking.

Recommendation

Current watershed conditions and upstream activities render water quality, biological, or geomorphic monitoring designed to detect water resource degradation from upstream sources, futile. Monitoring should be reevaluated if more intensive management or development becomes likely. No detectable impacts should be allowed to result from USFS activities in the headwaters as stated in Bandelier's enabling legislation.

8) Ungulates

Hoofed animals can negatively impact water resources by direct fecal contamination, destruction of streamside and riparian vegetation, trampling of stream banks, and promoting watershed erosion. At Bandelier, landscape carrying capacity is also a concern because of the highly erodible nature of the watershed.

Recommendation

Bandelier should continue its policy of excluding and eliminating feral cattle and burros. Current programs designed to monitor elk and mule deer populations and their impacts on vegetative communities should also continue.

9) Water Rights

Bandelier has two prior appropriation water rights and federal reserved water rights. The park currently has potable water supplied from the County of Los Alamos and may not continue to maintain the historic orchard. Most of the watershed for Frijoles Creek is included within park boundaries.

Recommendation

Bandelier should reconcile its future water needs with existing water rights to determine if additional rights should be secured or if any existing rights are not needed.

10) New Mexico Stream Designations

Extraordinary Resource Water (ERW) or Outstanding National Resource Water (ONRW) designation can be an important safeguard for park waters because they provide the highest level of protection within most state's hierarchies. While this designation provides added protection from external water resources degradation, it can also elevate pressure to alleviate internal degradation.

Recommendation

Bandelier should work with the Water Resources Division to pursue ERW or ONRW designation for Capulin and Alamo Creeks, possibly as part of a concerted National Park Service nomination for streams in New Mexico. This designation will have to be closely examined with regard to Frijoles Creek in light of the ongoing degradation near Monument headquarters.

11) Water Quality Monitoring

Managers have expressed concern that they are not adequately managing riparian habitat or assessing impacts from park operations and adjacent land use without a credible water quality-monitoring program. Current water resource investigations are focusing on specific management concerns through issue specific studies conducted by qualified specialists.

Recommendation

A water resource specialist on staff could develop long-term extensive studies to help develop a holistic understanding of Bandelier's water resources. However, given the current staffing, specific studies conducted by qualified personnel are the best alternatives. Numerous potential water quality studies have been identified in this plan.

12.) Recreation
Documented recreational impacts have only been confirmed in the headquarters reach of Frijoles Creek. Designation of the Jemez Mountains Recreation Area near Bandelier's upper watersheds could bring increasing recreational pressure to Bandelier and surrounding lands.

Recommendation
Water quality monitoring for fecal coliform bacteria in Frijoles Creek above Monument headquarters or within Capulin Canyon could serve as a surrogate for Monument-wide monitoring of wilderness water quality impairment.

13.) Road Salting
The New Mexico Department of Transportation applies road salt and cinders to Highway 4 in the headwaters of Frijoles Creek. Spring runoff of salt could be damaging soil properties, vegetative communities, and water quality.

Recommendation
Bandelier should perform a basic assessment of the effects of salt runoff into Monument waters by taking conductance readings above and below road areas during spring thaws and other times of the year.

14.) Atmospheric Deposition
Transport of nutrients and acid precipitation into Monument watersheds via atmospheric processes could damage vegetation and aquatic communities over large areas.

Recommendation
Review of rainwater chemistry data indicates no decrease in pH or increases in nutrients. These data did show a statistically significant downward trend for sulfate. The current atmospheric deposition monitoring should continue.

INTRODUCTION

Bandelier National Monument was established to preserve what remains of the area's once thriving Ancestral Puebloan culture. Springs, streams, and riparian zones allowed these ancient agrarians to flourish in an otherwise harsh landscape. The occurrence of water over a wide range of elevations and microclimates continues to support Bandelier's diverse assemblage of plants and animals, and provides the visitor from today's world a different manner of sustenance.

Water is often a significant resource in units of the National Park Service, either through support of natural systems, administrative use, or visitor enjoyment. The NPS seeks to perpetuate surface and ground water as integral ecosystem and wilderness components by carefully managing its consumptive use and striving to maintain the quality and health of aquatic ecosystems in accordance with all applicable laws and regulations. Water resources inventorying, monitoring, and planning are essential activities of park resource management.

National Park Service managers at Bandelier have assembled a diverse and competent resource staff. The purpose of this document is to assist this staff by summarizing the current knowledge regarding the area's water resources and by identifying, assessing, and making recommendations concerning pertinent water resource issues. Project statements have also been developed to help Monument staff address high-priority issues utilizing external funding or expertise (Appendix D). This Water Resources Management Plan (WRMP) was developed with the assistance of hydrologists from the National Park Service's Water Resources Division (WRD). Monument staff and area experts were consulted on numerous issues and a large volume of related literature was reviewed.

This WRMP begins by summarizing existing information about the area's natural and anthropogenic environment. Water resource issues are then presented within the context of the Monuments unique setting. Water resource issues discussed in this report include:

- Watershed Management
- Infrastructure
- Fisheries Management
- Los Alamos National Laboratory
- Cochiti Reservoir
- DDT
- External Impacts within Upper Watersheds
- Water Rights
- Ungulates
- Extraordinary Resource Waters Designation
- Water Quality Monitoring
- Recreation
- Road Salting
- Atmospheric Deposition

Recommendations are presented for each issue, which include alternative management actions, restoration programs, opportunities for improved inter-agency cooperation and further studies where resource knowledge is insufficient. Some issues, such as the impacts of Cochiti Reservoir, will require constant vigilance on the part of Monument personnel, continually evolving responses, and the overall realization that further drift from natural conditions is inevitable.

EXISTING RESOURCE CONDITIONS

This section provides the reader unfamiliar with Bandelier's physical and anthropogenic environs a context to analyze the issues and recommendations that follow. New insights and recent scientific discoveries are also discussed which should benefit even long-term staff. It also provides a concise record of current resource knowledge that new staff and managers can consult to familiarize themselves with the area's political setting, physical environs, and water resources.

Location and Adjacent Landownership

Bandelier National Monument is located in north central New Mexico (Figure 1) on the eastern slopes of the Jemez Mountains. The Monument consists of two noncontiguous units. The small Tsankawi unit (800 acres) was disregarded in this plan because of its limited water resources (ephemeral washes being the most predominant). The main unit, encompassing 32,827 acres, comprises 70 percent of the Monument's 47,100-acre contributing watershed. Bandelier's headquarters are within the lower Frijoles Canyon near Los Alamos, New Mexico.

The Valles Caldera and Sierra de los Valles are the central features of the Jemez Mountains. The highest elevations within Bandelier coincide with the eastern rim of the Valles Caldera. The Monument encompasses a portion of the eastern slopes of the Sierra de los Valles; part of the Pajarito Plateau and its canyons; and, extends down the west wall of White Rock Canyon to include the Rio Grande's west bank and riparian zone (Proc. No. 1991 - February 25, 1932 - 47 Stat. 2503).

Bandelier's most intensely developed neighbor is Los Alamos National Laboratory (LANL) to its north (Figure 2), encompassing 27,520 acres. LANL has been involved in numerous large-scale research and development projects, including nuclear reactors and weapons. LANL is almost exclusively outside the Monument's surface watersheds (Figure 2).

The northwestern and western boundaries adjoin the Baca Ranch, a 95,000-acre private cattle ranch which incorporates most of the Valles Caldera. The ranch also takes in portions of the Monument's uppermost watersheds. The National Park Service recently purchased another private tract in this same area, Elk Meadows.

The Monument's largest neighbor is the Santa Fe National Forest. National Forest lands include 13,900 acres of the Monument's western watersheds and the perennial headwaters of four streams. The Santa Fe National Forest also borders the Monument to the north and along the length of the Rio Grande. Monument lands adjacent to the Rio Grande are included within an easement granted to the U.S. Army Corps of Engineers which permits "flooding and inundation as is required for the operation of [Cochiti Reservoir] (NPS and U.S. Army Corps of Engineers, 1977)." The southern boundary is contiguous to lands owned by the University of New Mexico. These lands are entirely downstream from the Monument.

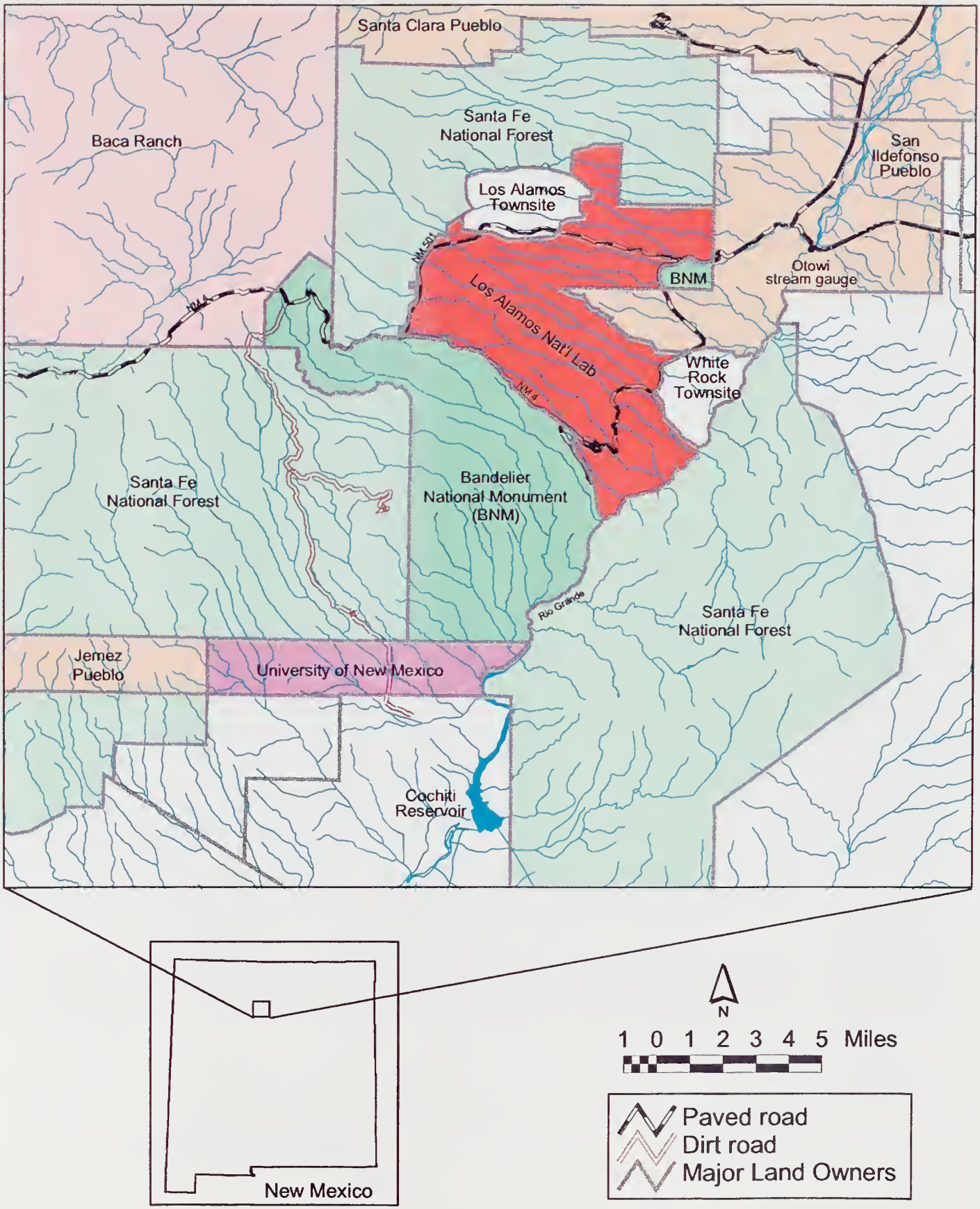

Figure 1. Regional Map, Bandelier National Monument. (Source: BAND-GIS)

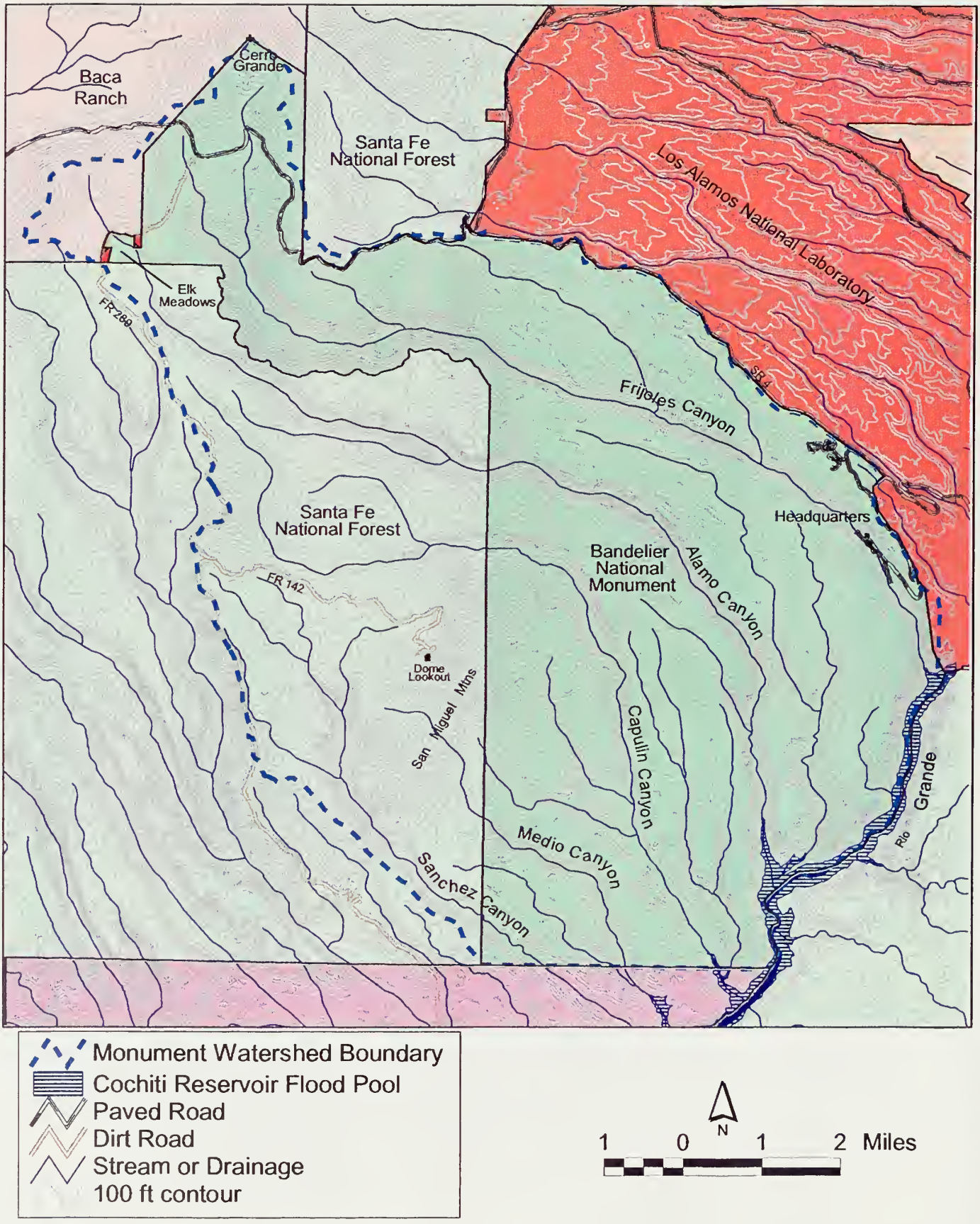

Figure 2. Main Unit of Bandelier National Monument, Surrounding Landownership, and Surface Hydrography. (Source: BAND-GIS)

Legislation and Management Philosophy

In 1916, Bandelier National Monument was established within the boundaries of the Santa Fe National Forest, with the U. S. Forest Service retaining administrative responsibility. The authorizing proclamation stated "certain prehistoric aboriginal ruins...are of unusual ethnologic, scientific, and educational interest, and it appears the public interests would be promoted by reserving these relics of a vanished people, with as much land as may be necessary for the proper protection thereof." (Proc. No. 1322 - February 11, 1916 - 39 Stat. 1764). In addition, the proclamation stipulated that forest operation should not impact the Monument by mandating "the National Monument hereby established shall be the dominant reservation, and any use of the land which interferes with its preservation or protection as a National Monument is hereby forbidden."

In 1932, administration of the Monument was transferred to the National Park Service (Proc. No. 1991 - February 25, 1932 - 47 Stat. 2503). However, the western boundary separating Bandelier and the Santa Fe National Forest remained a straight north-south line cutting across watersheds. Resource extraction and other multiple-use activities occurring in these headwaters under U.S. Forest Service direction have impacted Bandelier's streams. Attempts to transfer these headwaters to National Park Service administration have been made in the past. To date, only the Elk Meadows area (about 90 acres) has been acquired by the NPS (Sydoriak, pers. comm., Bandelier National Monument, 1999).

Boundary adjustments in 1959, 1963, and 1977, brought all but about 100 acres of the Rito de los Frijoles watershed into the Monument. Bandelier's current boundaries encompass 32,827 acres, with another 4,231 acres of the adjacent Cañada de Cochiti grant (currently University of New Mexico property) and approximately 835 acres of the Alamo headwaters (currently part of the Baca location) authorized by Congress for acquisition (Allen, 1989a; Sydoriak, pers. comm., Bandelier National Monument, 1999). In 1976 wilderness designation was applied to 23,267 acres (two-thirds) of the Monument (Public Law 94-567). Ninety percent of Bandelier is managed as backcountry (National Park Service, 1995a).

In December, 1993, Bandelier's staff created the following Mission Statement to direct park management efforts:

> *To preserve, protect, understand, and enjoy the cultural and natural resources of Bandelier National Monument* (Sydoriak, pers. comm., Bandelier National Monument, 1999).

The overarching natural resource goals are to:

(1) provide the means and opportunity to study, understand, and enjoy the resources of the Monument without unduly compromising the resources or ethnographic value; and,
(2) preserve, protect, and manage cultural and natural resources to promote self-sustaining environmental conditions and the information they represent, as existed prior to modern human influence (i.e., prior to landscape-level livestock grazing and wildlife suppression and following Ancestral Puebloan occupation of the area.

To this end, the park has the following desired future conditions:

(1) natural and cultural resources are promoted and preserved within naturally-functioning and sustainable environmental conditions as existed prior to modern human influence; and,
(2) information on the cultural and natural resources is accurate, accessible, secure, and comprehensive.

Federal Laws, Executive Orders, and National Park Management Directives dealing with water resources and applicable to Bandelier and are summarized in Appendix A.

Climate and Vegetation

Bandelier's climate is classified as a semi-arid, temperate, continental mountain climate. However, the area's elevation gradients which range from 5,300 to 10,199 feet, combined with variances in slope, aspect, and topography, produce significant climate and vegetative changes (Allen, 1989a). Average precipitation increases from 9 inches at lower elevations to as much as 30 inches along the crest of the mountains (Purtymun and Adams, 1980). Mean annual precipitation at Bandelier's weather station is about 16 inches.

Post-1924 droughts recorded at Bandelier include an extreme drought from 1953 to 1956, culminating with only 4.9 inches of precipitation in 1956. Cyclic El Niño climate events bring increased spring and summer precipitation to this area about once every 4 years (Allen, 1989a).

Figure 3 shows monthly average temperature and precipitation patterns on the Pajarito Plateau and at a lower elevation near the Rio Grande. July is the warmest month and January is the coldest. The average July temperature at the lower elevations is 73° F and on the plateau 66° F, while average January temperatures along the river are 22° F and on the plateau 19° F.

Precipitation events are often localized, varying significantly along the length of the elongated drainage canyons within the Monument (Stevens, 1996). Roughly 40 percent of the precipitation occurs during intensive convective storms during the July and August "monsoon" season. These summer thunderstorms have been responsible for the most extensive surface erosion and highest flood peaks on record (Reneau et al., 1996a). A dry period usually extends from late April through the end of June (Allen, 1989a), largely as a result of increased evapotranspiration as opposed to decreased rainfall.

Evapotranspiration (ET) measurements show that the major water loss from the Pajarito Plateau is through ET, which varies annually between 79 percent and 100 percent of total precipitation. The average ET ratio is considered to be 87 percent. Additional evapotranspiration acts on what little flow reaches canyon bottoms through even higher rates of vegetative transpiration. Water balance studies conducted at Los Alamos National Laboratory (1998b) show that as a result of transpiration, storage in alluvial sediments, and downward migration to deeper water bearing zones, there is very little stream flow leaving LANL.

The Jemez Mountains are at the southernmost extension of the Rocky Mountain Forest Province, with vegetative communities similar to those found throughout the southern Rocky Mountains (Table 1). Juniper-grass lands with Russian olive, willow, cottonwood, and salt cedar are found along the Rio Grande (Figure 4). Willow patches are currently expanding along the Rio Grande

where sediment deposition is occurring in the slack waters formed by Cochiti Reservoir. Riparian forests also extend along canyon drainages where perennial flows or shallow alluvial waters exist.

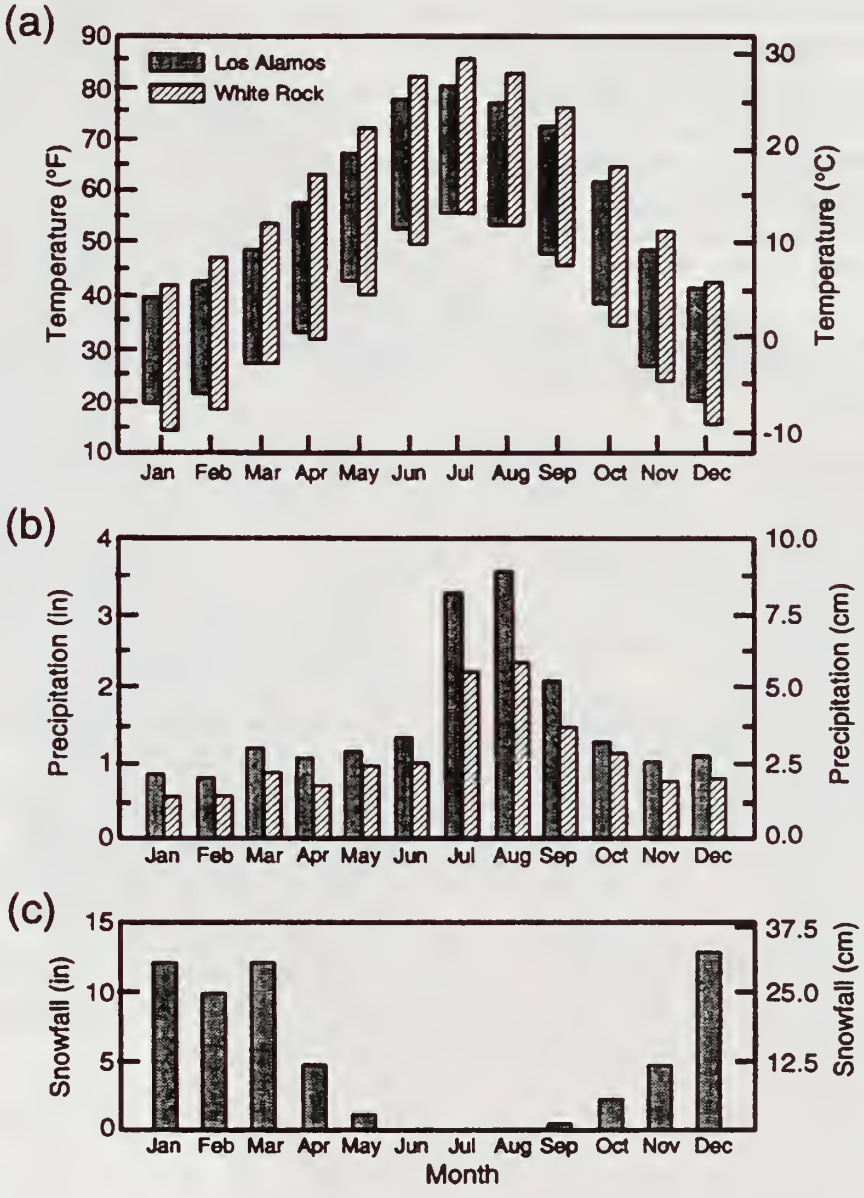

Figure 3. Monthly (a) Temperature Range, (b) Precipitation, and (c) Snowfall at Los Alamos (1961-1990) and White Rock (1965-1990), New Mexico (Reneau and McDonald, 1996).

Xeric communities are found in the eastern two-thirds of the Pajarito Plateau and are dominated by piñon and juniper. The western third and lower slopes of the mountains are covered with pine, spruce, and fir. At the highest elevations, aspen and pine occur on northerly exposures while alpine meadows are found on south-facing slopes (Allen, 1989a). Vegetative communities

have been subjected to a variety of significant human influences, particularly grazing and fire suppression (National Park Service, 1995a).

Piñon-juniper communities currently occupy nearly 10,000 acres within Bandelier. Intensive livestock grazing beginning around 1880 probably initiated a transformation from open, grassy, savanna communities to piñon-juniper scrublands. Overgrazing reduced the continuity of fine grass fuels and effectively prevented fire from propagating in piñon-juniper woodlands. Gottfried et al. (1995) and Allen (pers. comm., Bandelier National Monument, 1998) provided evidence of periodic fire in woodland systems prior to 1880 and documented the effects of the subsequent loss of the fire regime.

Table 1. Major Vegetative Communities at Bandelier National Monument (modified from Allen, 1989a).

ELEVATION (m)	VEGETATIVE COMMUNITY	DOMINANT SPECIES
1600-1900	juniper grasslands	juniper (*Juniperus monosperma*) *Bouteluoa* sp.
1900-2100	piñon-juniper woodlands	piñon (*Pinus edulis*) juniper
2100-2300	ponderosa pine forests	ponderosa pine (*Pinus ponderosa*)
2300-2900	mixed conifer forests	ponderosa pine Douglas-fir (*Pseudotsuga menziesii*) white fir (*Abies concolor*) aspen (*Populas tremuloides*) limber pine (*Pinus flexilus*)
>2900 (north)	spruce-fir forests	Engelmann spruce (*Picea engelmanni*) corkbark fir (*Abies lasiocarpa var. arizonica*)
>2900 (south)	high-elevation grasslands	*Festuca thurberi* *Danthonia parryi*

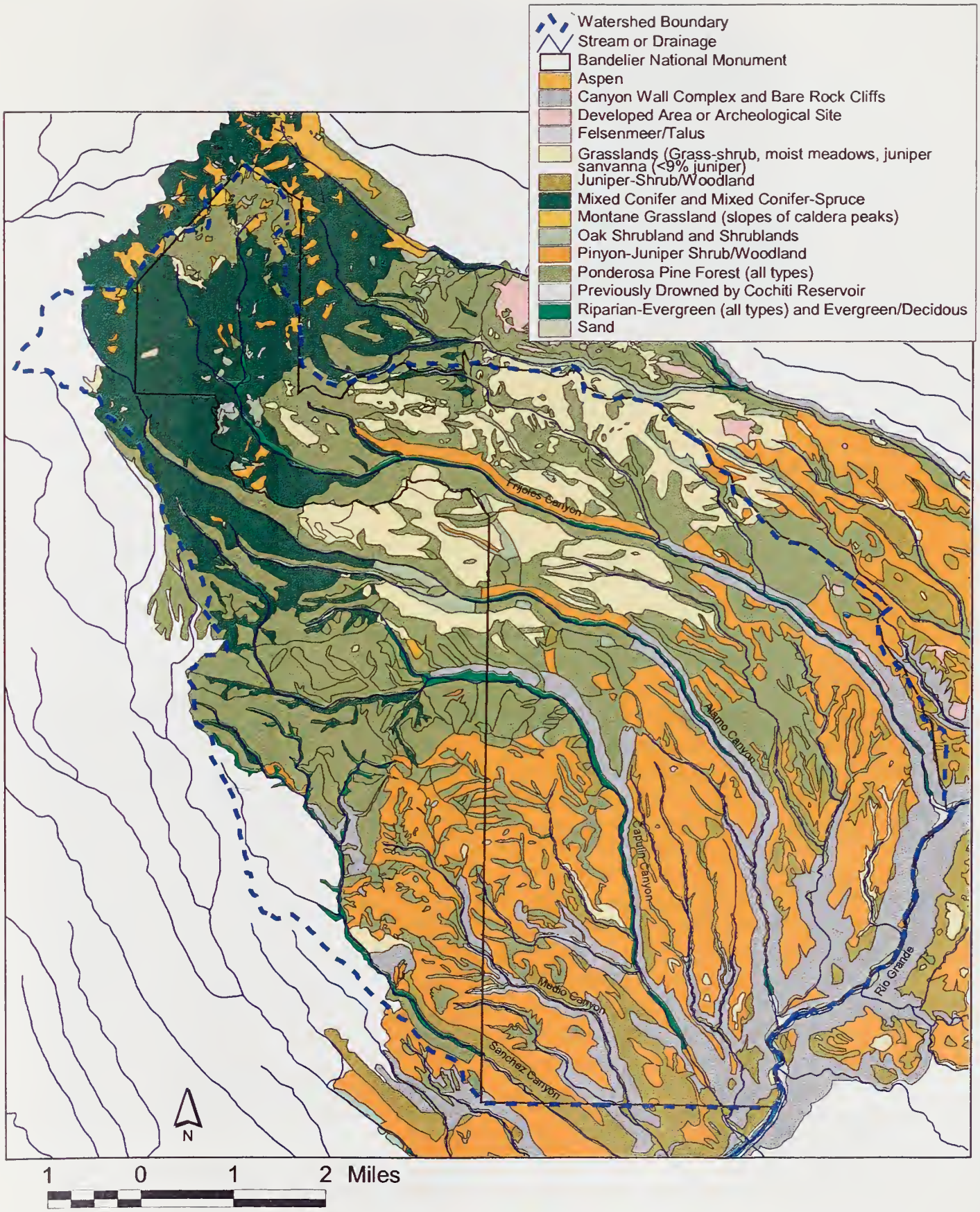

Figure 4. Major vegetative communities (as of 1981) at Bandelier National Monument. Some communities have been subsequently altered in places by events such as the Dome Fire in 1996. (Source: BAND-GIS)

Figure 5. Physiography of the Valles Caldera Region (Barry, 1990).

Physiography

Bandelier lies on the southeast flank of the Valles Caldera, the central feature of the Jemez Mountains (Figure 5). The Jemez Mountains are a complex volcanic pile at the intersection of two regional geologic features: the eastern rim of the Colorado Plateau to the west, and the Rio Grande rift to the east (Christensen, 1980). The Sierra de los Valles are the mountains encircling the caldera's rim. Streams draining the caldera form a radial drainage pattern (Figure 6). Drainage patterns at the scale of the Monument include: dendritic drainage pattern in headwaters; parallel drainage pattern across the Pajarito Plateau; and trellis drainage pattern within individual canyons (White and Wells, 1984).

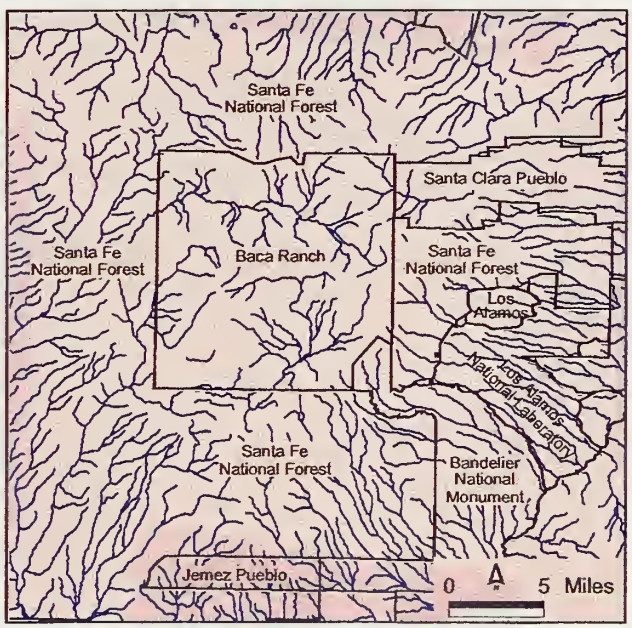

Figure 6. Radial Drainage Pattern Formed on the Valles Caldera (Source: BAND-GIS).

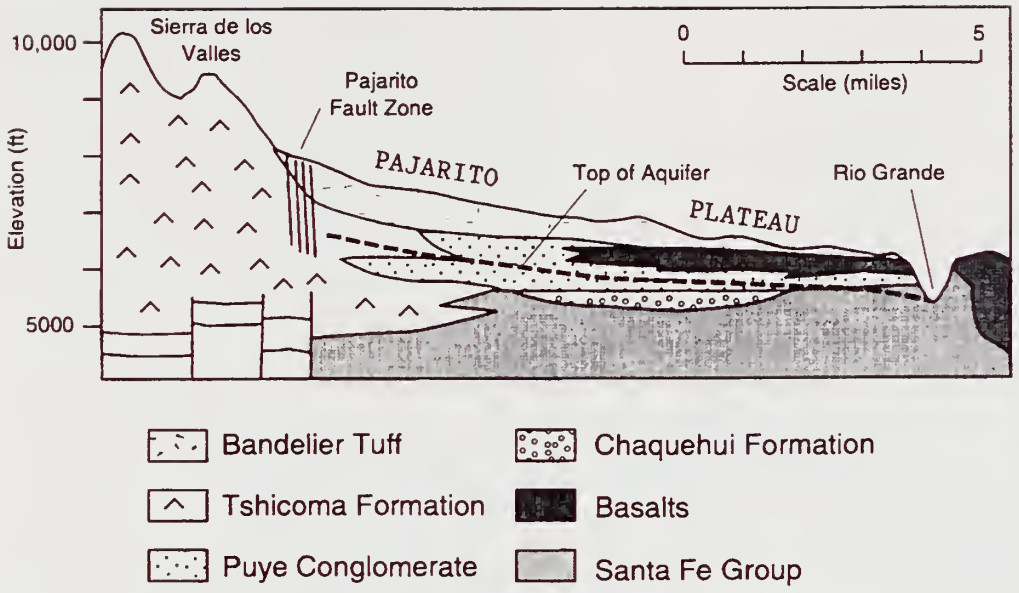

Figure 7. Cross-Section from the Jemez Mountains to White Rock Canyon (McLin et al., 1996).

The east flank of the Sierra de los Valles breaks to the gentler slope of the Pajarito Plateau, on which lies the majority of Bandelier (Figure 7). The Plateau is composed of gently sloping volcanic ash and lava flows and is terminated on the east by the deep canyon of the Rio Grande. The Pajarito Plateau has been dissected (in some places completely) by deep canyons. Between the canyons are elongated mesas, the surfaces of which share a common elevation and slope, and are remnants of the once continuous lava-flow. While the Bandelier country looks rugged and broken, most points have moderate slopes of less than 20 percent, with extremely steep slopes found on the near-vertical canyon and valley walls (Allen, 1989a). The San Miguel Mountains are an additional area of steep terrain (Figure 2) formed by an uplifted fault block of volcanic and sedimentary rocks lying southeast of the Valles Caldera.

Geology

Bandelier National Monument lies within an area of great crustal tension with a long history of volcanism; consequently, its surficial geology is predominantly volcanic extrusives (Figure 8). Sedimentary rocks are found on the east edge of the San Miguel Mountains and in the bottom of Capulin Canyon. Quaternary gravels (alluvium) occur in lower reaches of the canyons and along the Rio Grande River. East of the Rio Grande are a group of cinder cone vents forming the Cerros del Rio (Figure 5). These cones erupted 3 million years ago filling ancient valleys with basalt.

The Jemez Mountains are the remnants of a large, collapsed volcano that underwent massive eruptions 1.4 and 1.1 million years ago. The 6-mile wide Valles Grande (central crater) was formed by an explosion believed to have been 600 times as powerful as the Mt. Saint Helens eruption (Barry, 1990). Lava and ash from these eruptions covered the older basalt to a depth of

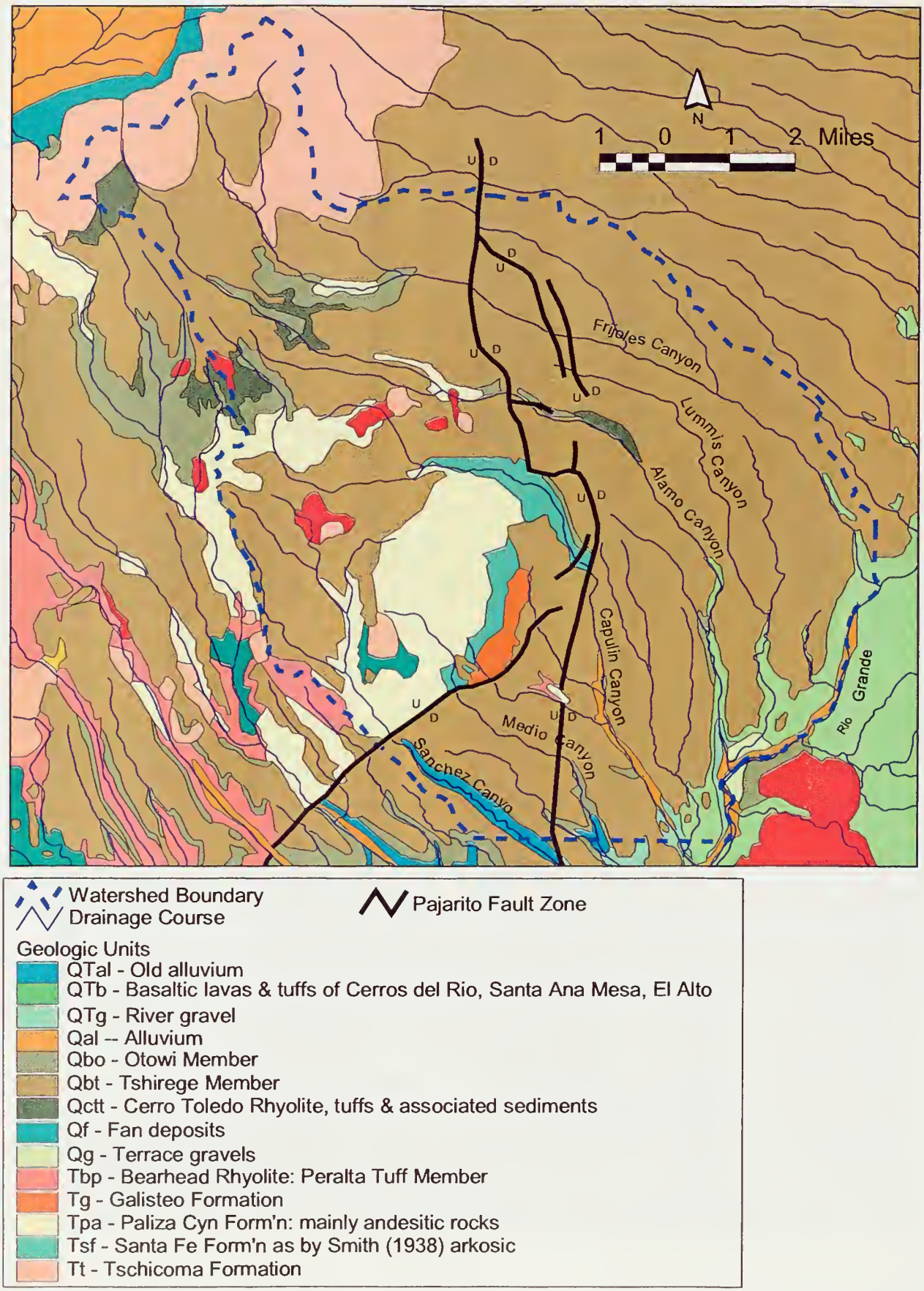

Figure 8. Surficial Geology at Bandelier National Monument. (Source: BAND-GIS)

1,000 feet in some places and formed the Pajarito Plateau. The Rio Grande has cut through the tuff and into underlying units to form White Rock Canyon.

Ash fall, pumice, and rhyolite tuff comprise the Pajarito Plateau and its cliff forming units, and together are referred to as the Bandelier Tuff. Most of the Monument's elongated mesas are comprised of this tuff which is over 1000 ft thick in the western part of the Plateau and thins to about 260 feet eastward near the Rio Grande. To the west, the tuffs overlap onto the Tschicoma Formation, which consist of older volcanics that form the Jemez Mountains (Los Alamos National Laboratory, 1995).

In most areas, the Bandelier tuff is underlain by the Puye Formation. The Puye is primarily a large Pliocene alluvial fan complex derived from the erosion of the Tshicoma highlands in the geologic past (Reneau and McDonald, 1996). In the eastern portion of the Pajarito Plateau, near White Rock Canyon, basalt flows from the Cerros del Rio outcrop and underlie the Bandelier Tuff. In lower Frijoles Creek, channel incision is impeded by the Cerros del Rio basalts such that the middle and upper Frijoles are not directly influenced by changes in Rio Grande base level (Reneau et. al., 1996a). Sedimentary rocks are exposed in the lower elevations of White Rock Canyon and in the canyon floors of the western Monument, and include sandstones and siltstones of the Miocene Santa Fe Group (Cannon, 1997).

The only aquifer capable of producing large-scale municipal water is referred to as the regional, or main aquifer, the surface of which rises westward from the Rio Grande within the Santa Fe Group and into the lower portion of the Puye Formation (Figure 7). The presence of numerous basalt flows interbedded in the Santa Fe Group may account for confining conditions noted in portions of this aquifer. Near the top of the Santa Fe Group and underlying the center of the Pajarito Plateau appears to be a late Miocene trough 3 to 4 miles wide and extending 7 to 8 miles from the northeast to the southwest. It is filled with up to 1500 feet of gravels, cobbles, and boulders and produces the area's only high-yield, low-drawdown water supply wells (Los Alamos National Laboratory, 1998b).

Alpine glaciers did not form in the Jemez Mountains (Allen, 1989a). Rather, streams draining from topographic highs dissected the relatively soft tuff and formed the narrow canyons and valleys of the Monument. Flowing water cut up to 1,000 feet in the tuff, and in places, up to 200 feet into the underlying basalt and sedimentary strata (Barry, 1990).

Major faults along the western boundary of the Monument resulted from crustal adjustments associated with the Rio Grande rift (Purtymun and Adams, 1980). The series of normal faults shown in Figures 7 and 8 are part of the Pajarito fault system, a system of over 65 miles of mapped faults. This concentrated fault zone is 0.25 miles wide and has over 410 feet of displacement, with the down-dropped wall to the east (Los Alamos National Laboratory, 1998b). Seismic hazard studies indicate the Pajarito fault system could produce maximum earthquakes with a Richter magnitude of about seven. Although large uncertainties are inherent to such studies, Richter magnitude earthquakes greater than or equal to six were estimated to occur once every 4,000 years along the Pajarito fault zone. Other work indicates additional faulting underlying and pre-dating the Bandelier Tuff (U. S. Department of Energy, 1998).

Soils and Erosion

Several distinct soils have developed as a result of interactions between bedrock, topography, and localized climatic conditions. Soil orders found at Bandelier include Entisols, Inceptisols, Alfisols, Mollisols, and Aridisols (Allen, 1989a). General soil surveys have been conducted by Earth Environmental Consultants (1978) for Bandelier, and specific soil surveys have been completed at a watershed erosion monitoring site located on the mesa south of the headquarters (Davenport, 1997). Detailed soil mapping has been completed for Los Alamos County, the adjoining Santa Fe National Forest, and Los Alamos National Laboratory (see references in Mathien et. al., 1993; and Allen, 1989a), but not for Bandelier National Monument.

The two most important properties of soils at the watershed scale are their infiltration rate and erodability. Soils in the area generally have a moderate to high infiltration rate due to the widespread occurrence of pumaceous and other highly porous parent material. Kearl et al. (1986) determined that pumaceous and other highly porous units within the tuffs of the Pajarito Plateau "act like a sponge", and require a quantity of water equal to approximately 1/4 of the rock volume to satisfy capillary forces and permit movement of water. Erosion hazard ranges from moderate to severe depending on soil characteristics, slope, effective ground cover, and overstory vegetation conditions (Cassidy et al., 1996). When soil infiltration thresholds are exceeded, sheet and rill runoff can cause widespread soil erosion augmented by the intensity of the area's thunderstorms and the low specific gravity of pumice (i.e. pumice floats).

Soil loss at Bandelier has been estimated at nearly one inch per decade; an unsustainable rate given soil depth in piñon-juniper woodlands is only one to three feet to bedrock (National Park Service, 1995b). Piñon-juniper woodlands cover 40 percent of the Monument and their high erosion rates are apparently due to their degraded state (Allen, 1989a). At least 80 percent of Bandelier's archeological sites within the pinyon-juniper zone are being damaged by accelerated erosion (National Park Service, 1995a).

Re-establishment of herbaceous ground cover in degraded piñon-juniper woodland areas is extremely difficult due to soil movement, soil loss, unreliable precipitation and an inadequate seed source. Major factors limiting restoration include: 1) restrictions on methodology as imposed by cultural, natural and wilderness values; 2) poor site conditions characterized by sparse vegetative cover, organic and nutrient poor soils prone to frost heave and high rates of erosion, depleted soil seed bank and limited seed source; 3) unreliable growing season precipitation or protective winter snow pack; and, 4) heavy utilization of existing herbaceous vegetation by wildlife ranging from ants to elk (National Park Service, 1995a).

Current and abandoned roads and trails can be focal points for accelerated erosion throughout the watersheds. The infiltration capacity of road and trail surfaces is low, and little precipitation is required to generate runoff. This runoff is often channeled down the surface of the road or trail, or within road ditches, at erosive velocities. Recent studies reviewed by Castro and Reckendorf (1995) reveal the density and extent of a basin's drainage are increased because the roads and trails act as ephemeral tributaries, creating a more efficient sediment delivery system.

WATER RESOURCES

Surface Water

The entire Monument drains to the Rio Grande and Cochiti Reservoir (Figure 1). The Rio Grande is the master stream in north central New Mexico and south central Colorado, with a drainage area above Otowi of 14,245 mi^2. The discharge at Otowi for 94-years of record (1902-1996) ranged from 60 cfs in 1902 to 24,400 cfs in 1920, with the average flow being 1,530 cfs (U.S. Geological Survey, 1998). As mentioned previously, the eastern boundary of the Monument is defined as the westbank of the Rio Grande; therefore, a detailed discussion of the hydrology of the Rio Grande is immaterial. Alteration of natural flows within the Rio Grande do affect Bandelier's riparian areas, flood plains, and wildlife, and are discussed in later sections.

Five principal canyons dissect Bandelier's portion of the Pajarito Plateau in a northwest to southeast alignment (Figure 9). These canyons support various lengths of base flow (Table 2) which originate from springs and seeps along the mountain/plateau interface (Table 3). The two most prominent streams, Capulin and Frijoles, have average base flows of approximately 0.5 and 1.0 cfs, respectively. Only Rito de los Frijoles (translation = Little River of the Beans - referred to in the text as Frijoles Creek) maintains perennial flow to the Rio Grande. In addition to the major canyons, six discrete areas on the western wall of White Rock Canyon drain mesa tops and side slopes directly to the Rio Grande (Stephens, 1982).

Table 2. Stream Information for Bandelier National Monument's Canyons (compiled from Purtymun and Adams, 1980).

Name	Location of Headwaters	Drainage Area ($mi.^2$)	Perennial Reaches*	Average Gradient* (ft/mi.)
Chaquehui Canyon	Pajarito Plateau	1.8	M	all = 475
Frijoles Canyon	Sierre de los Valles	19.8	U,M,L	U=397;M,L=158
Lummis Canyon	Pajarito Plateau	7.6	None	all = 211
Alamo Canyon	Sierre de los Valles	19.1	U,M,L_p	U=397;M,L=211
Capulin Canyon	San Miguel Mountains	19.6	U,M,L_p	U=317;M,L=211
Medio Canyon	San Miguel Mountains	6.6	U	U=686;M,L=211
Sanchez Canyon	San Miguel Mountains	7.7	M	U=422;M,L=211

* U = Upper, M = Middle, L = Lower, L_p = Portion of Lower

Table 3. Information for Selected Springs at Bandelier National Monument (compiled from Purtymun and Adams, 1980).

Name	Location	Average Flow (gpm)*	Character	Comments
Doe Spring	Upper Chaquehui	small	large seep	forms pools
Turkey Spring	Capulin Canyon	22.2	spring	perennial flow
Spg at head of	Frijoles Canyon	231	spring	perennial flow
Apache Spring	Frijoles Canyon	0.96	spring	perennial flow
Spg near mouth of	Frijoles Canyon	1.38	spring	silted over
Alamo Spring	Alamo Canyon	small	seep	silted over

* gpm = gallons per minute

Christensen (1980) stated the springs and seeps which supply base flow to Monument streams are recharged from perched water in the Tschirege member of the Bandelier Tuff, or within the underlying Tschicoma formation. These perched bodies are found in fractured or jointed rock, or in a pumice bed at the base of the Tschirege. Recharge is thought to occur on the southeast flank of the Sierra de los Valles. Christensen determined perennial flow in stream channels is maintained when the infiltration rate of water into canyon alluvium does not exceed the amount of water supplied by springs and seeps. Evapotranspiration and loss to underlying formations mainly control stream channel infiltration rates.

Purtymun and Adams (1980) noted that stream flow increased in Frijoles Canyon from the springs to the crossing of the Pajarito fault line (upper crossing of trail). They attributed this increased flow to return flow from thinning alluvium, seepage from colluvium at the base of the canyon walls, and movement of water through brecciated zones associated with the faults. Surface flow decreased from the fault line to the confluence with the Rio Grande. They also reported intermittent reaches of Frijoles Creek during some summers.

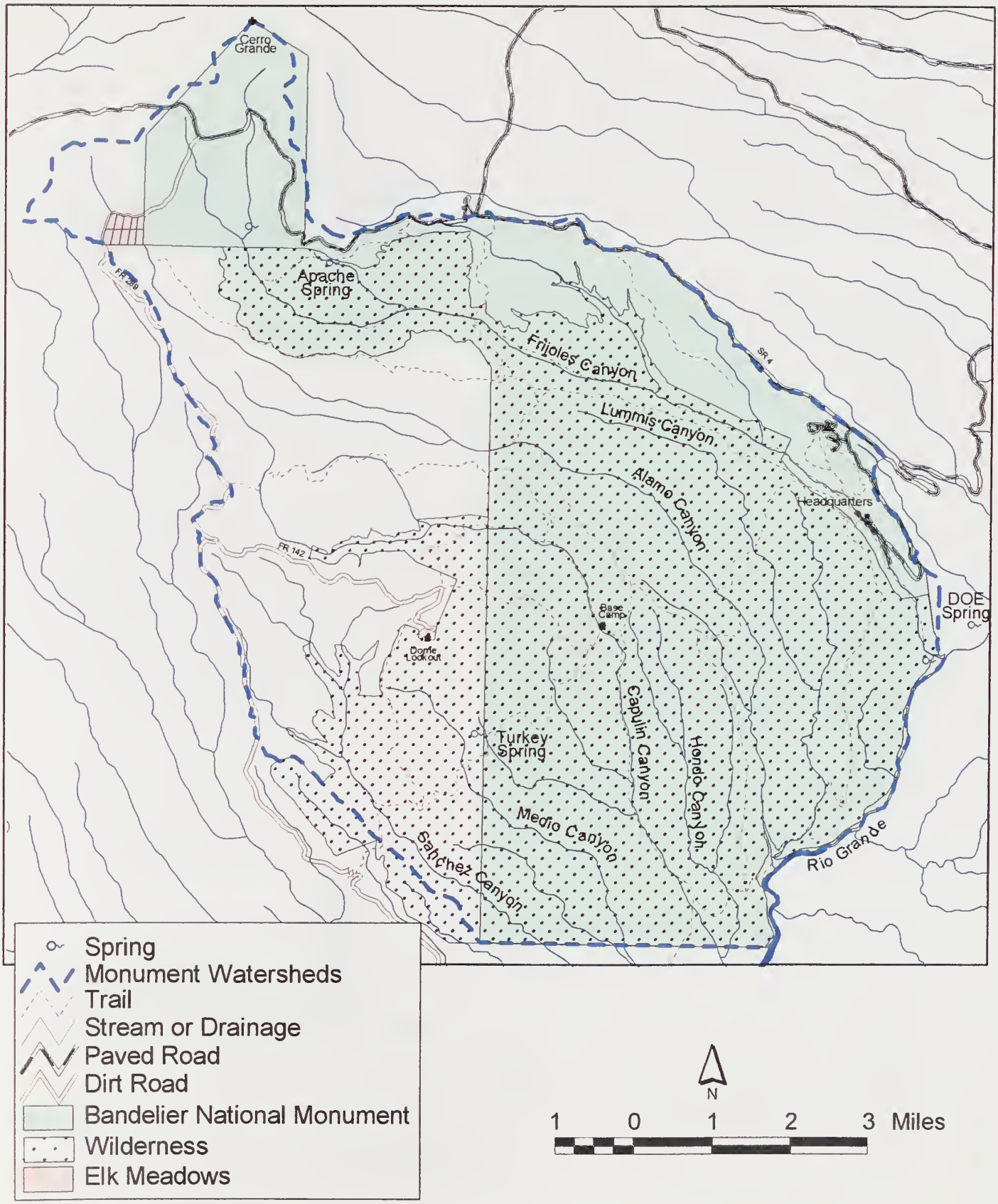

Figure 9. Surface Drainages and Springs at Bandelier National Monument. (Source: BAND-GIS)

A surface water gauging station was operated near the upper crossing of Frijoles Creek during 1960 to 1962. The drainage area above the station was 8.9 mi^2. The short period of record at this gauge makes it of limited value. The gauge was moved downstream to 3,600 feet above Monument headquarters in July 1963. This station monitored a drainage area of 17.5 mi^2 and operated continuously until September 1969.

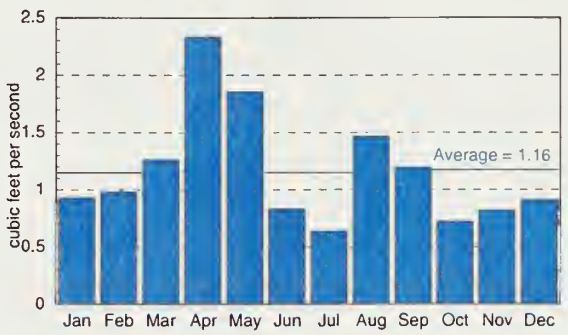

Figure 10. Average Monthly Flows in Frijoles Creek, 1963 to 1969 (USGS data).

Figure 10 shows the mean monthly flows for the six years and two months the Frijoles gauge operated. In spite of the "dry period from late April through the end of June" reported by Allen (1989a), April and May produce the highest average flows. High flows in spring result from snowmelt passing down the canyon, which, as shown in Figure 3, is not directly receiving increased precipitation. Average stream flow drops until August when recurrent thunderstorms (monsoon) produce runoff events.

Also shown on Figure 10 is the average annual flow calculated for the six-year gauging interval. This value, 1.16 cfs, has a discharge versus drainage area ratio of 0.07 cfs/mi^2. For comparison, eastern streams average 1.0 cfs/mi^2 and semi-arid western streams about 0.8 cfs/mi^2 (Leopold, 1994). The fact that the Frijoles average annual flow is an order of magnitude less than regional predictions is testimony to the area's low precipitation, high soil permeability, and efficient evapotranspiration. Frijoles Creek is also characterized by low maximum discharges (Figure 11). Maximum flows in a high relief southwestern canyon setting such as Frijoles would be expected to have a greater magnitude, and reflect both the watershed's ability to "act like a sponge" (Kearl et al., 1986) and its highly elongate shape.

Measurements which highlight how unusually low maximum discharges are in Frijoles Creek include recurrence interval, discharge, and drainage area relationships provided by Leopold (1994) for the Rio Grande basin as shown in Figure 12. The return interval of 2.33 years for a watershed encompassing 17.5 mi^2 should exceed 100 cfs, while a ten-year event should exceed 200 cfs. In contrast, the highest observed maximum flow in Frijoles Canyon over the six-year reporting period was only 19 cfs. Similarly, the highest peak flow observed over nine years of monitoring in Capulin Creek was only slightly greater than 21.8 cfs.

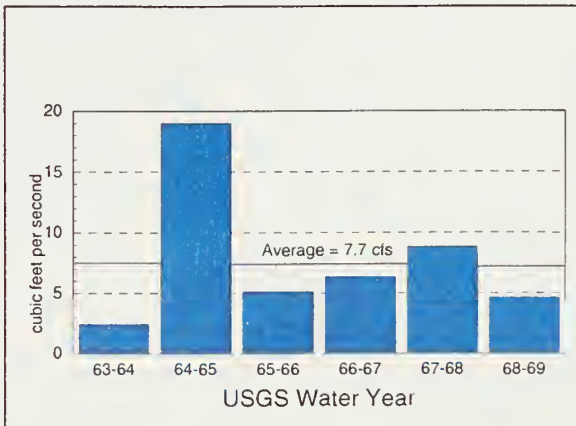

Figure 11. Maximum Yearly Flows in Frijoles Creek (USGS data).

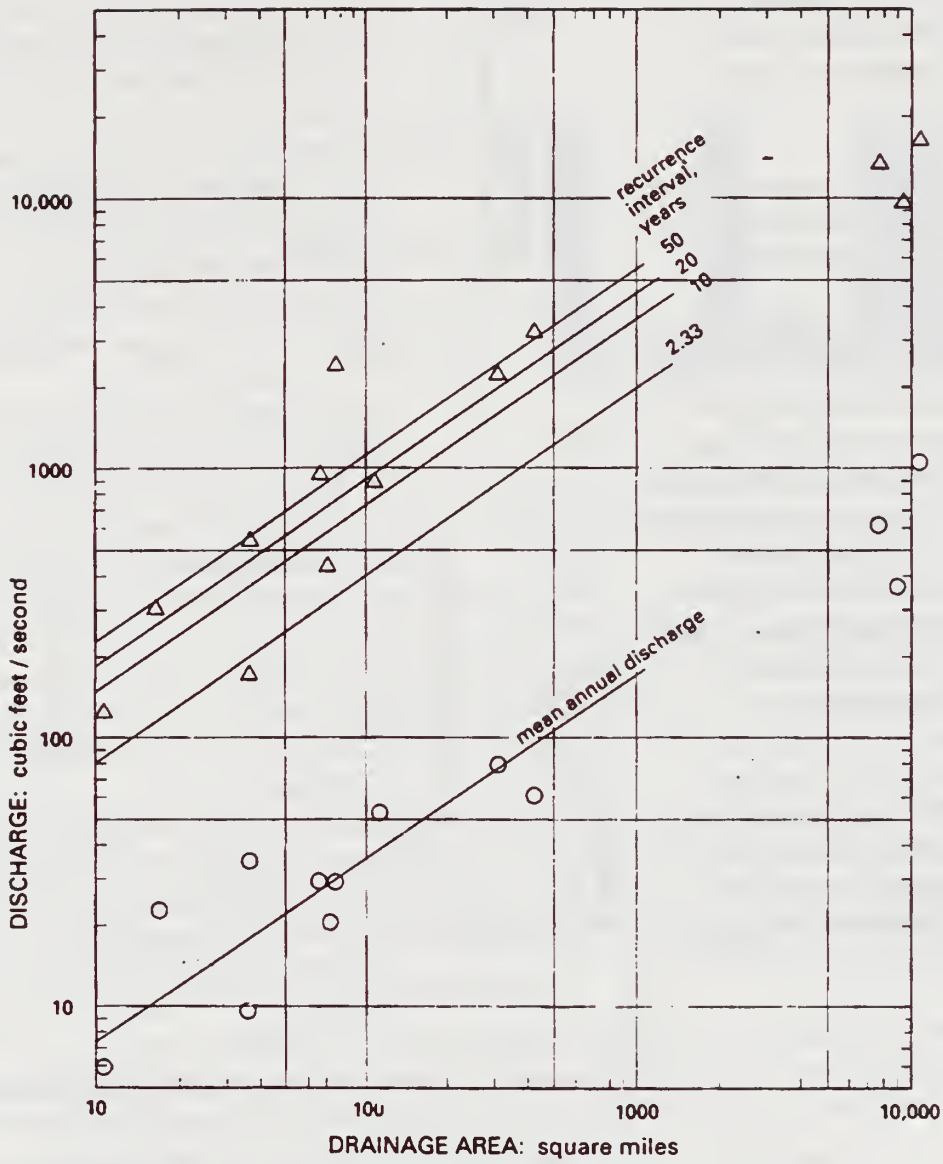

Figure 12. Discharge Recurrence Intervals as a Function of Drainage Area for Rio Grande Basin (Leopold, 1994).

Another regional example can be extrapolated from a U.S. Army Corps of Engineers (1979) return interval graph for flows of various magnitudes. Their analysis of the Santa Fe River and Arroyo Mascaras near Santa Fe, New Mexico, indicate the two-year return flow should be at least 85 cfs for a 17.5-mi^2 watershed.

The runoff characteristics of the Frijoles basin changed radically as a result of the June 1977 La Mesa Fire. The La Mesa Fire consumed about 15,000 acres of piñon, juniper, spruce, aspen and pine in and adjacent to the Monument (Purtymun and Adams, 1980). About 58 percent of the Frijoles Creek drainage above the headquarters was consumed by this predominantly intense crown fire. One month after the fire, a new gauging station and a concrete flume were installed on Frijoles Creek about 800 feet downstream from Monument headquarters. This station

monitored an 18.1-mi^2 drainage and was operated continuously by the United States Geological Survey (USGS) until 1982.

Post-burn stream-flow records exhibit distinct changes from the six-year pre-burn record, with the number, magnitude, and frequency of peak flows increasing significantly (White and Wells, 1984). In 1977, 1978, and 1979, there were 15, nine, and five peak flows, respectively, above the pre-fire maximum peak discharge of 19 cfs. Of these peak flows, seven in 1977, seven in 1978, and three in 1979 were over 100 cfs (Veenhuis, 1998). The largest events were 1,800 and 3,124 cfs (95 and 164 times greater than the pre-burn peak, respectively), and occurred in the same month, July 1978. Purtymun and Adams (1980) analyzed pre- and post-burn streamflow records and determined "Runoff in 1978 was similar to years 1964-69. Though it

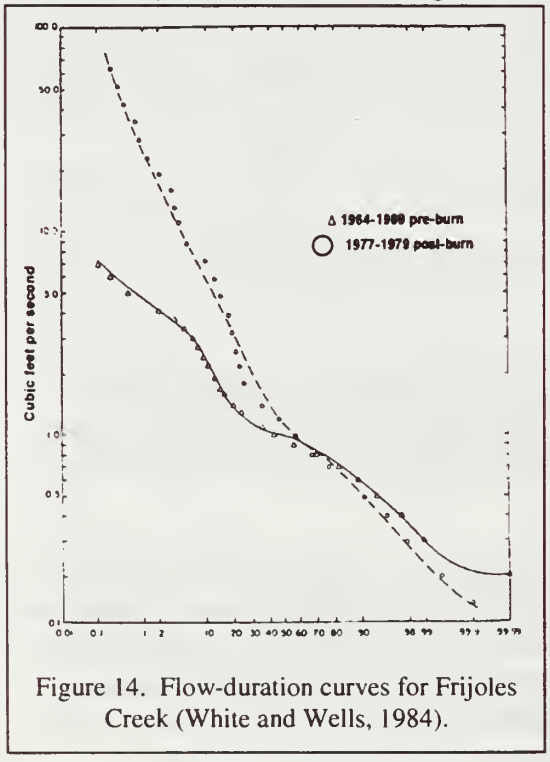

Figure 14. Flow-duration curves for Frijoles Creek (White and Wells, 1984).

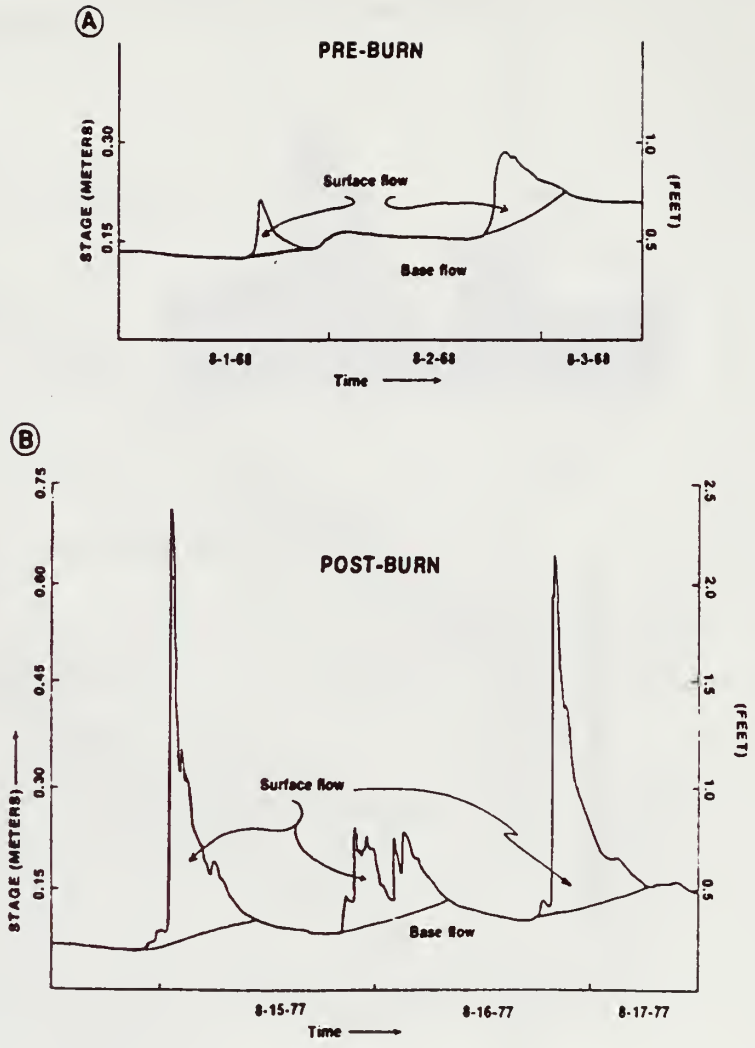

Figure 13. (a) Pre- and (b) post-La Mesa Fire hydrographs for Frijoles Creek (White and Wells, 1984).

appears that the volume of runoff has not changed, the time of collection and retention of precipitation in the drainage area has decreased. This resulted in larger discharge from runoff events."

Figure 13 indicates the post-burn hydrograph is flashier, with sharper, higher magnitude flood peaks, and steep limbs. The post-burn hydrograph illustrates a much larger surface component; whereas, the pre-burn hydrograph has a greater base-flow component. The variability of stream-flow can also be described by a flow-duration curve (Figure 14). The flow duration curve displays the frequency at which flows of various magnitudes are equaled or exceeded. Figure 14 indicates that 60 percent of the time the

post-burn discharge of Frijoles Creek is greater than the discharge of the same frequency for the pre-burn record. Furthermore, 10 percent of the time the flow of the post-burn record exceeds the 0.1 percent frequency event of the pre-burn record. Figure 14 also shows high-frequency base-flow events are smaller since the La Mesa fire (White and Wells, 1984).

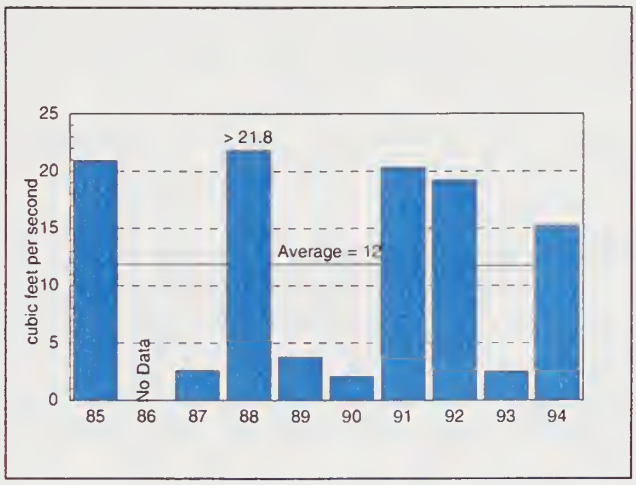

Figure 15. Annual Peak Flows for Capulin Creek (Veenhuis, 1998).

Similar hydrograph relationships were observed following the Dome wildfire, which burned approximately 16,500 acres of National Forest and National Park Service lands in the spring of 1996. Nearly the entire Capulin Canyon watershed was burned at varying intensities during this fire (National Park Service, 1996a). Peak flow records are available for Capulin Canyon just upstream from Base Camp for a period of 10 years, including 1985, and 1987 to 1994 (Figure 15). While the maximum pre-fire discharge was slightly greater than 21.8 cfs, the estimated peak for the maximum post-fire flow event was 2,700 cfs (Veenhuis, 1998).

A final observation which rules out large precipitation events as the cause of flooding is flooding was not reported from Capulin Canyon during 1977 through 1979 when the large floods occurred on Frijoles Creek. Similarly, if we use Frijoles as the control basin during the post-Dome Fire period, flooding was not observed in Frijoles Creek after 1996, in sharp contrast to Capulin Creek's behavior during this same time.

Ruby (1998) provided a watershed condition survey (probable runoff and sedimentation response) for the Tsankawi Unit of Bandelier National Monument. He divided the Unit into seven "watersheds" totaling 797 acres. Each watershed was rated for condition using "Fair", "Poor", and "Very Poor" categories.

Ground Water

Ground water beneath the Pajarito Plateau occurs in three zones: the shallow alluvium of canyons; perched on relatively impermeable strata; and in the main aquifer (Los Alamos National Laboratory, 1995). The main, or regional, aquifer is the only viable water source on the Pajarito Plateau (Rogers et. al., 1996b). Almost everything that is known about the area's ground water comes from investigations conducted by or for Los Alamos National Laboratory. Despite the millions of dollars and years of effort spent on sampling, modeling, and quantifying subsurface waters, these systems remain a conundrum.

Purtymun and his associates (Purtymun and Cooper, 1969; Purtymun and Johansen, 1974; Purtymun and Adams, 1980; Purtymun, 1984; Purtymun et al., 1989) conducted much of the early ground water investigations in the area. This work resulted in a conventionally acceptable model of ground water recharge and flow that had the following premises:

1) Water in canyon alluvium is recharged by perennial, intermittent, or ephemeral stream flow. Once in the alluvium, it moves down canyon and is depleted mainly through evapotranspiration;

2) Springs in the upper canyons arise from perched water bodies. Perched ground water beneath the Pajarito Plateau is recharged from the eastern slopes of the Valles Caldera;

3) Water in the main aquifer is under water table conditions in the western and central part of the plateau and under artesian conditions in the eastern part and along the Rio Grande. Major recharge to the main aquifer is from the intermountain basin of the Valles Caldera in the Jemez Mountains west of Los Alamos. The water table in the Caldera is near land surface. The underlying lake sediments and volcanics are highly permeable and contribute to the recharge of the aquifer through the Tschicoma Formation interflow breccias and the Tesuque Formation;

4) Ground water flow within the main aquifer is toward the Rio Grande River (Figure 7). Water levels in the aquifer are higher than the river level north of the mouth of Frijoles, and about 20 springs and seeps discharge to the river within this gaining section of the Rio Grande River. Downstream from the confluence with Frijoles Creek the water table drops below the channel of the Rio Grande resulting in a losing reach;

5) Based on the gradient of the potentiometric surface and hydrologic characteristics of the aquifer, the rate of water movement within the main aquifer is estimated to be about 393 ft/yr. Depth to the top of the main aquifer at Monument headquarters is estimated to be 354 ft;

6) The main aquifer is isolated from the alluvial and perched waters by 350 to 620 feet of dry tuff and volcanic sediments. Thus, on the Pajarito Plateau, there is little hydrologic connection or potential for recharge to the main aquifer from alluvial or perched water; and,

7) The hydrologic characteristics of the unsaturated tuff forming the Pajarito Plateau can retain or arrest the movement of water-soluble contaminants originating from liquid or solid wastes stored in the tuff.

While the above description of subsurface water remains generally valid, the details regarding recharge and hydraulic connectiveness among the three zones of ground water, and between surface infiltration and these zones, have been significantly altered by subsequent researchers. Reevaluation was triggered by the detection of contaminants in each of the three ground water bodies (Los Alamos National Laboratory, 1998b). Some examples of these modifications follow and are numbered to correlate with the above discussion:

1) Zones of perched water exist beneath most, if not all, of the wetter canyons of the Pajarito Plateau. These perched bodies are recharged by intermittent and perennial stream flow loss to alluvial sediments and, ultimately, underlying volcanics (Los Alamos National Laboratory, 1995; Los Alamos National Laboratory, 1998b);

2) Drilling at the western boundary of Los Alamos National Laboratory did not detect a laterally extensive perched ground water zone. Fracture transmission may be responsible for recharge to

the springs, with the actual source of this water remaining unknown (Los Alamos National Laboratory, 1998b);

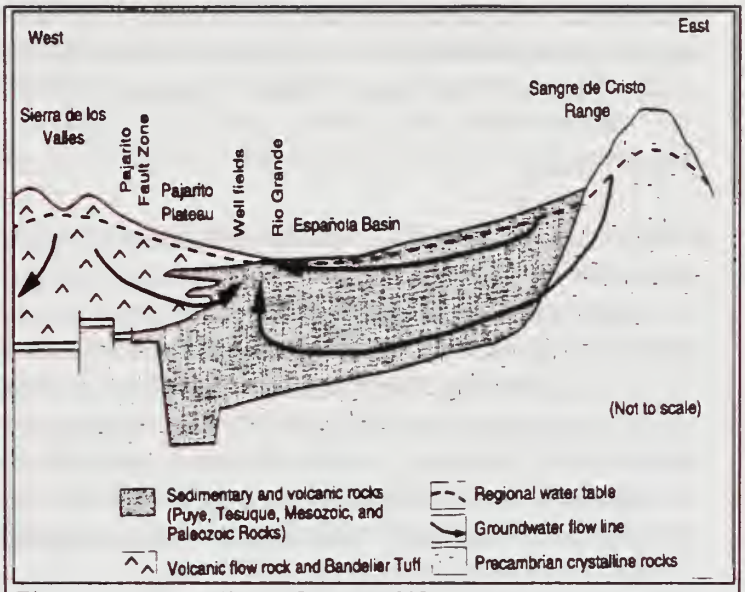

Figure 16. Idealized Ground Water Flow Pattern Near Los Alamos (McLin et al., 1996).

3), 4) and 5) Blake et al., (1995) concluded that the Valles Caldera is not the source of recharge to the Los Alamos well field. They concluded most aquifer recharge comes from the Espanola Basin or other regions to the north. Stable isotope analysis (Goff and Sayer, 1980; Vuataz and Goff, 1986) and age dating of main aquifer water (Rogers et al., 1996b) indicates that part of the aquifer is recharged from the Sangre de Cristo Mountains, and that a ground water divide lies west of the Rio Grande (Figure 16). Analysis of spring water geochemistry within White Rock Canyon along the Rio Grande shows the presence of numerous constituents commonly found in explosives and trace levels of depleted uranium, and may be related to intermediate perched water (Los Alamos National Laboratory, 1998b) as opposed to recharge from the main aquifer;

6) and 7) Ground water sampling summarized by the U.S. Department of Energy (1998) documented a myriad of contaminants in alluvial and perched ground water, many of which exceed EPA or New Mexico water quality criteria. Even in the main aquifer, tritium, plutonium-239 and -240, americium-241, and strontium-90 have been detected, as well as organic compounds and nitrates. Because these products were originally discharged to canyon streams or buried on mesa tops, as opposed to injected directly to ground water bodies, their presence in monitoring and production wells confirms vertical migration through unsaturated deposits. Mechanisms allowing this vertical migration are described by Rogers et al. (1986a) and Turin and Rosenberg (1996) and involve fracture, fault, joint, surge bed and other permeable unit through-flow under canyons or mesas during the wetter seasons.

The purpose of this condensed discussion is two-fold: 1) to demonstrate the complexity of the hydrogeologic systems below the Pajarito Plateau and allude to the widespread occurrence of contaminants beneath LANL; and, 2) to illustrate the evolving nature of the scientific understanding of these systems and their contaminant attributes. Recent monitoring and assessment of ground water by Los Alamos National Laboratory and the state of New Mexico reveal laboratory management practices, especially past practices, relied too heavily on the area's geohydrologic ability to assimilate, contain, or entrap contaminants.

In some cases this dogma continues as illustrated by the following quote taken from a *Response to New Mexico Environmental Department request for supplemental information on the Hydrogeologic Workplan* which states "...the tuff beneath the alluvium is unsaturated. It is well

established by hydrologists that in the case of unsaturated water flow, **fractures and joints are a barrier to aqueous flow**. Fractures and joints can only contain and transport water if the entire rock is saturated" (emphasis added, Vozella, 1998, p. 35).

Water Quality

Because the Rio Grande is outside Bandelier's boundary and has a large contributing watershed which the NPS cannot realistically influence, water quality in the river will not be reviewed in this document. Some discussion will be presented concerning sediments deposited by the river because these are accumulating on Monument lands. In a recent water quality review conducted by the National Park Service (1997), results from Rio Grande water quality sites in the vicinity of the Monument were analyzed and the reader interested in Rio Grande water quality should consult that document. Within Bandelier, natural water quality conditions should be maintained "unimpaired" under the pretense of the National Park Service Organic Act (1916, 16 USC 1). Water quality standards relative to Bandelier are guided by the Clean Water Act as promulgated by the State of New Mexico (New Mexico Water Quality Control Commission, 1995) and declare:

> *Perennial tributaries to the Rio Grande in Bandelier National Monument and their headwaters...*
>
> *Designated Uses: domestic water supply, high quality cold water fishery, irrigation, livestock watering, wildlife habitat, municipal and industrial water supply, secondary contact and primary contact.*
>
> *Standards: In any single sample: conductivity shall not exceed 300 umhos, pH shall be within the range 6.6 to 8.8, temperature shall not exceed 20 °C (68 °F), and turbidity shall not exceed 10 NTU. Other use specific standards apply and natural background occurrences of some parameters may exceed these standards.*
>
> *The monthly geometric mean fecal coliform bacteria shall not exceed 200 col/100 mL.*

According to the National Park Service (1997), water quality has been sampled from a total of 34 stations within Bandelier, with 20 of these sites on Frijoles Creek. Thirteen sites have long-term records consisting of multiple observations dating as far back as 1957. The National Park Service (1997) used Environmental Protection Agency and NPS Water Resources Division screening criteria to evaluate these water data. This screening found the metals copper, lead, and zinc exceeded EPA acute freshwater criteria in lower Frijoles Creek. It should be noted that freshwater criteria are hardness-based and calculated for a hardness of 100 mg/L as $CaCO_3$. Therefore, these excedences may be more or less severe than indicated depending on the actual hardness of the streams (Rosenlieb, pers. comm., 1999).

The principal ions in Bandelier's streams are calcium and bicarbonate with the water typical of mountain streams in the area with total dissolved solids (TDS) ranging from 84 to 168 mg/L. One of the first intensive water quality studies (Purtymun and Adams, 1980) focused on post-fire water quality perturbations and indicated a slight increase in calcium, bicarbonate, chloride,

fluoride, and TDS in the base flow of Frijoles Creek. Storm flow samples showed elevated suspended sediment, barium, calcium, iron, bicarbonate, manganese, lead, phenol, and zinc concentrations. Phenol is attributed to the decay of vegetation. Other constituents can be attributed to runoff from the burned area, or in the case of lead, possibly from automobile emissions. Base-flow water quality returned to normal 3 to 5 years after the fire.

Park-based water quality monitoring has been attempted intermittently in the past, mostly during a ten-year period from 1982 to 1992. Parameters were sampled at nine to 16 stations and included: pH, conductivity, air and water temperature, dissolved oxygen, alkalinity, organic carbon, and turbidity. Biological parameters including total fecal coliform counts, fish tissue and bed sediment analyses for organics, and aquatic invertebrate surveys were occasionally performed. Discharge measurements were not taken; however, gauging stations located on Frijoles and Capulin Creeks provide stage height records for two of the water quality stations (National Park Service, 1995a). Stage data at the Frijoles station have subsequently been converted to flow by the U.S. Geological Survey as part of the National Park Service funded NAWQA efforts.

Park-based sampling attempted to develop a base-line water quality data set, assess potential external impacts, and determine if backcountry recreation or headquarters development (sewage system, horse corral, picnic area, pit toilets, maintenance compound, etc.) were impacting water quality. Probably the most sensitive parameter related to these goals is fecal coliform bacteria. Fecal coliform measurements were made every two weeks from six stations along the developed portion of Frijoles Creek during 1976 to 1978, 1982 to 1985, and 1993 to 1994 (National Park Service, 1995a).

Sampling in the headquarters reach occasionally found fecal coliform levels in excess of 3,000 colonies per 100 milliliters (col/100mL), apparently documenting intermittent sewage system failures. Subsequent measurements appear to indicate rapid flushing of fecal coliform from the system. Purtymun et al. (1988) detected the compound *bis* (2-ethylhexyl) phthalate in Frijoles Creek at a level of 560 ug/L. Phthalates are common in surface waters receiving sanitary effluent and the Frijoles concentration is equivalent to levels measured below a sewage treatment plant in Los Alamos County (National Park Service, 1995a). Historical documentation of other potential sources of coliform contamination (i.e., visitor use, pit toilets, horse corrals, paved and dirt parking lots, picnic areas, wildlife) is more problematic.

Bracker (1995) interpreted the results of bacteria samples collected from Frijoles Creek on 27 recording dates between December 7, 1993 and December 5, 1994. Samples were collected at eight different sampling stations; the most upstream was at the Wilderness Boundary above Ceremonial Cave, and the most downstream was below the horse corral. These samples were tested for fecal coliform and fecal streptococcus bacteria. Bracker concluded:

- Bacterial contamination of the stream rises markedly during the warm summer months when visitation is highest. Unfortunately, turbidity was not measured. When turbidity and fecal coliform bacteria exhibit a positive correlation, it provides evidence that adsorbed bacteria is either being re-suspended with stream sediments (i.e. from visitors wading in the stream above the sampling station) or washed in from nonpoint sources. When a correlation

between turbidity and bacteria is weak, it indicates the bacteria are in solution and probably result from point sources or ground water.

- There is an erratic tendency for Frijoles Creek to become more contaminated as it flows through the heavily used part of the canyon. In some cases there is a marked increase in bacteria counts at a specific point. This may indicate that discrete events (spills at the lift station, spillovers at the corral due to heavy rain...) are being observed. In other cases, there is a slow steady degradation in water quality throughout this portion of the stream.

- A characteristic pattern seems to be low readings at stations one to four (above the visitor center) and high at stations five to eight (below the visitor center). This pattern is most evident when the overall contamination is fairly low. On one occasion, there was a fairly abrupt rise between stations four and five.

- After two days of rain, bacteria counts are consistently high, and spike very high at the horse corral (stations 7 to 8). Runoff of manure-laden water into the creek was suspected. The yearly highs seem to fall in July when summer rains typically begin. After August, the trend is dramatically downward (as is visitation).

Bandelier developed a strategy to mitigate contamination from the Frijoles horse corral and implemented it in 1995 (Jacobs, pers. comm., 1998). Mitigation included routing surface runoff from the drainage area above the horse corral around the corral, frequent clean-up and removal of waste, and boarding the horses outside the canyon when they are not needed for backcountry patrols. A follow-up study by Stevens (1996) investigated water quality above and below horse corrals on Frijoles and Capulin Creeks using benthic macroinvertebrates, fecal coliform, physical characteristics, and several water chemistry parameters. The objectives were to provide information on benthic macroinvertebrate community structure, assess potential impacts from the horse corrals, and examine the relationship between benthic macroinvertebrate community structure and physicochemical parameters (Stevens, 1996).

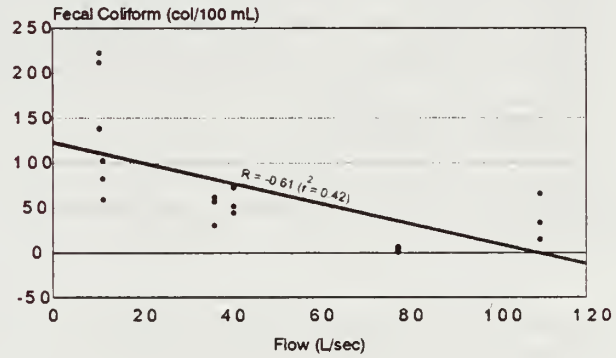

Figure 17. Fecal Coliform Bacteria as a Function of Flow in Frijoles Creek (Stevens, 1996).

No significant differences were found in water chemistry or fecal coliform upstream and downstream of either horse corral. In general there was an inverse relationship between fecal coliform counts and flow in Frijoles Creek (Figure 17) which is indicative of a point source. This relationship was not observed in Capulin Creek. Unfortunately, Stevens did not look at turbidity or total suspended solids, which should correlate highly with fecal coliform counts in a nonpoint setting. There were no single fecal coliform samples with over 2,000 colonies/100 mL (Stevens, 1996).

All measured physicochemical parameters were in general agreement with previous water quality monitoring in Frijoles and Capulin Creeks. Nitrate concentrations were typically very low in both streams, with 50 percent of the samples below the detection limit of 0.01 mg/L in Frijoles Creek and 80 percent of the samples below 0.01 mg/L in Capulin Creek. Nitrates were relatively high at all three sites on Frijoles Creek (0.280, 0.280, and 0.333 mg/L) in December 1996. Ammonium samples were always below the detection limit of 0.001 mg/L, except at all six sampling locations of both streams in August, when concentrations jumped to 0.6 mg/L. At least in the case of the anomalous ammonium results, lab contamination or other quality control problems are suspect.

The U. S. Geological Survey's National Ambient Water Quality Assessment Program (NAWQA) measured water chemistry, bed sediment, fish tissue and stream flow from a reach of Frijoles Creek just below the visitors center over a three-year interval beginning in April, 1993. The water sampled was a well-oxygenated, sodium calcium magnesium bicarbonate type. The median specific-conductance value was 108, the median pH value was 7.8, and the median DO saturation was 98 percent. Dissolved solids and most major constituents were in the low group as compared to other sites in the Rio Grande study unit, chloride was in the middle group, and silica was in the high group. In fact, the minimum silica concentration detected in Frijoles Creek was equal to the maximum observed from all of the other sites combined. These large silica concentrations are probably the result of weathering of volcanic tuff in the drainage basin (Healey, 1997).

Nitrogen species median values reported through NAWQA were below detection limits. Total phosphorus was also very low and dissolved phosphorus and orthophosphate were in the middle group. Dissolved iron concentrations were in the high group, much larger than expected for well-oxygenated surface waters (Healey, 1997). Because of the extent of mineralization in the Rio Grande basin, relatively high arsenic, cadmium, copper, lead, mercury, selenium, and zinc concentrations in water and bed-sediment samples probably represent natural conditions (Carter, 1997a). Trace element concentrations in bed sediment at Frijoles Creek were within the range observed for all Rio Grande basin NAWQA study sites, and below USGS-determined background concentrations with the exception of beryllium. Beryllium had the maximum concentration of 4 µg/g. This maximum value is not considered to be significantly different from other sites, and it is noted that beryllium in fish tissue was less than the detection limit at this same site (Carter, 1997b).

Purtymun et al., (1987) reported on radionuclides in river sediments of the Rio Grande, including one site on the Rio Grande below the confluence with Frijoles Creek. Data interpretation was lacking in this report, but a cursory review of data tables did not reveal any notably high concentrations. Environmental surveillance conducted by Los Alamos National Laboratory in 1990 (LANL, 1992) included radiochemical analysis of sediments from Frijoles at Bandelier headquarters. The highest total uranium concentration (5.2 µg/g) and gross gamma counts (4.7 counts/min/g) of 36 sites sampled were reported from Frijoles. The total uranium values are below the EPA Primary Drinking Water Standards (20 µg/L) and surface water samples collected later were even lower in total uranium (1.0 µg/L). All other radionuclide parameter concentrations were low and the uranium concentrations found in the sediments could also be

due to natural sources (LANL, 1996). A detection of contaminant derived from high explosives was reported in Frijoles Creek at low levels by LANL researchers in 1996 (Gallaher, 1998).

Cochiti Reservoir

The Middle Rio Grande Conservancy District (MRGCD) constructed four major diversion dams by 1935, including Cochiti. The Cochiti diversion was subsequently included in flood/sediment control efforts for the Rio Grande Valley through the 1960 Flood Control Act (PL86-645). In 1964, PL#88-293 authorized the Secretary of the Interior to provide a permanent pool at the Cochiti dam site for the development of "fish and wildlife resources, conservation and recreation purposes." An enlarged dam, designed to support the multi-purpose mandate, was completed in 1973. It is a rolled earth fill embankment with a crest length of about 5 miles and a crest height of 250 feet. The dam is located about 6 miles downstream of the Monument (Bullard and Wells, 1992).

Before the construction of Cochiti Dam, the Rio Grande near Bandelier was a transitional reach within the lowest section of White Rock Canyon. Within the canyon, the river was a relatively high-energy, high-gradient, fast flowing stream, confined by canyon walls and colluvium and relatively stable. Below White Rock Canyon the river was aggrading and had many channels separated by bars and islands composed of course gravel and cobbles (Bullard and Wells, 1992).

Cochiti Dam holds Rio Grande flood waters, primarily during spring runoff events, and annually drowns the entire reach of the Rio Grande adjacent to the Monument and up to 350 acres of NPS lands (National Park Service, 1995a). This flooding is allowed under a Memorandum of Understanding (MOU) signed March 25, 1977, between the National Park Service and the U.S. Army Corps of Engineers, which permits a maximum flood-pool contour of 5,465.5 feet.

Cochiti Reservoir's mandated recreation pool extends about 6.5 miles upstream from the dam, while the flood pool extends 20 miles upstream and inundates several riparian landholders. A total of 9,621 acres of flood easement was acquired for project purposes from the U.S. Forest Service (8,236 acres), Atomic Energy Commission (345 acres), National Park Service (361 acres), University of New Mexico (540 acres), and private concerns (139 acres) (U.S. Army Corps of Engineers, 1995).

Figure 18 shows the wedge of sediments accumulating in upper Cochiti Reservoir. The average sedimentation rate is 1,189 acre-feet per year (Gallegos, 1998). Approximately 27,341 acre-feet of sediment had accumulated by 1998, utilizing 27 percent of the reservoir's 105,000 acre-feet sediment reserve. At the 1976-1998 rate of sediment accumulation, the design storage will be fully utilized by 2063. U.S. Army Corps of Engineers estimates predict this reservoir will be completely filled with sediment in about 500 years (Allen, 1989a).

Figure 18. Longitudinal Profile of Sediment Accumulation in Cochiti Reservoir (Gallegos, 1998).

Corps of Engineers staff (Kreiner, pers. comm., Corps of Engineers, 1998) indicated that the rate of sedimentation should be slowing due to construction of upstream reservoirs and better land use management in the contributing watershed, although this is not supported by the slope of the upper line in Figure 19.

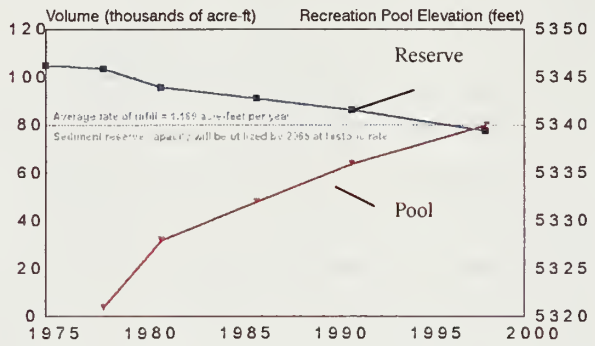

Figure 19: Historic Recreational Pool Adjustments and Sediment Reserve in Cochiti Reservoir (Gallegos, 1998).

P.L. 88-293 requires maintenance of an open-water permanent pool of 1200 surface acres behind Cochiti Dam. Because the expanding sediment delta consumes open-water surface area, pool levels must be routinely adjusted upward, re-flooding encroaching sediments (Figure 19). The chronic result of this process is permanent flooding, with water followed by sediment, of that portion of the Monument below the re-adjusted permanent pool.

From a regional perspective, aggradation of sediments in the Rio Grande channel and adjacent flood plain was formerly a natural phenomenon that combined with multiple, meandering stream channels and non-diverted water flows to provide a variety of wetland environments in the riparian zone. Most of the Rio Grande's native wetland habitats have been lost through such human activities as: diversion of water, alteration of the river channel, regulation of river flows and sediment loads with dams, and degradation of the river channel downstream from reservoirs due to the interruption of natural sediment loads. River deltas at the head of major reservoirs provide one of the few remaining opportunities to maintain such near-stream wetland habitats (Allen et al., 1993).

The ecological character of the flooded portions of the Monument is continually changing as Cochiti Reservoir fills with sediment. The growing delta has the potential to become a valuable wetland habitat, thus offsetting a portion of the regional wetlands loss (Allen, 1989a). The delta currently attracts thousands of migrating waterfowl each year. Threatened and endangered species also use the area including bald eagles and peregrine falcons, and the delta may also be used by whooping cranes during their spring and fall migrations (Allen et al., 1993). However, the irregular flooding regime of Cochiti Reservoir, sometimes including 100-foot rises above the former river level and almost year round duration (Figure 20), reduces the potential productivity of this area as wildlife habitat (National Park Service, 1995a).

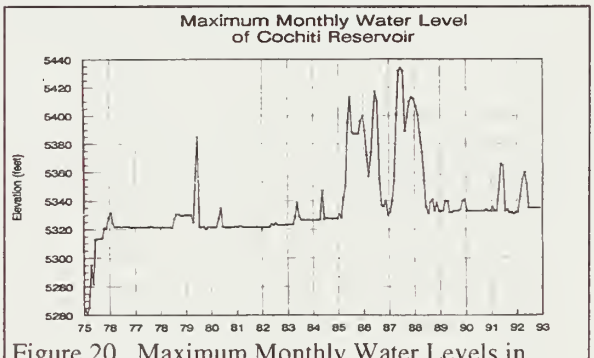

Figure 20. Maximum Monthly Water Levels in Cochiti Reservoir (Allen et. al., 1993).

Wetlands And Riparian Zones

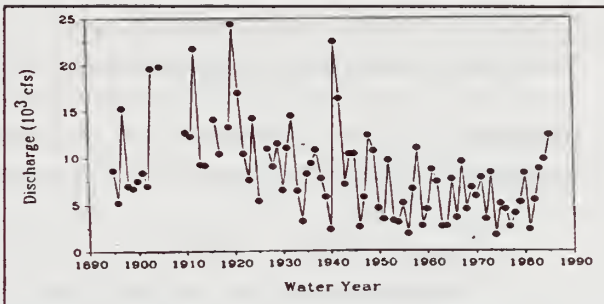

Figure 21. Historical Flood Peaks on the Rio Grande River (USGS data).

Flooding along the Rio Grande, primarily associated with spring snowmelt, was formerly a critical determinant of successional patterns in the riparian zone. The river valley provided the majority of Bandelier's nesting and foraging habitat for migrating shorebirds and waterfowl, along with cover for grazing species. However, the Rio Grande's flow has long been modified, even before the filling of Cochiti Reservoir (Figure 21). Diversions, most notably the Abiquiu project on the Rio Chama, modified the natural hydrograph. Reduced peak flows, altered sediment regimes, and other factors changed the Rio Grande's fluvial dynamics and flood plain ecology.

Potter (1981) stated most of Bandelier's native high quality riparian areas were effectively buried by sedimentation within Cochiti's backwaters. Riparian and other vegetative communities within the flood easement included barren flat and sandbar (14 percent), juniper shrub (74 percent), shrub grass (two percent), juniper cottonwood (six percent) and juniper-cottonwood-pine (four percent). Above average runoff in the winter of 1978 to 79 resulted in the raising of Cochiti Reservoir's surface elevation from a normal pool of 5,322 feet to 5387.5 feet for about 75 days (Figure 20). Riparian areas, river terrace, and lower juniper slopes were inundated by floodwaters killing most of the vegetation. Local deposits of silt up to five feet deep occurred between Frijoles and Lummis Canyons (Potter, 1981).

The Rio Grande's cottonwood trees died because they are adapted to only a limited amount of submergence in their normal role as a riparian tree. Receding silt-laden water coated woody vegetation such as cholla and junipers about a quarter of an inch thick. Burial of a floristicly diverse spring at the mouth of Frijoles Canyon apparently caused the direct extirpation of six plant species from the Monument (Allen, 1989a). The apparent death of all herbaceous and woody vegetation in the inundated area produced an unattractive, desolate appearance. Landslides and slumps also affected areas above the maximum reservoir level (Potter, 1981). Deposition of layers of river sand and silt provided a favorable medium for pioneer plant succession, including a variety of introduced agricultural weeds and riparian exotics.

The sediment deposited at the head of Cochiti Lake is forming a vast delta and associated wetlands. Wetlands comprised 199 acres in the delta area in 1991. The growing delta wetlands are ecologically valuable due to the widespread destruction of wetlands in the Rio Grande corridor and throughout the southwest. Allen et al. (1993) believe that with proper management, the Cochiti delta can develop into one of the most ecologically significant wetlands in New Mexico, with great benefits for local wildlife, migratory waterfowl, several threatened and endangered species, fisheries, and human enjoyment. Unfortunately, continual pool adjustments to maintain the reservoir's 1200-acre surface area recurrently submerge the wetlands. For example, permanent pool adjustment in 1992 inundated one quarter of the developing wetland.

Flood plains and riparian zones also occur along intermittent and perennial streams in the Monument's canyons. Riparian vegetation is maintained where phreatophytes have access to a dependable supply of alluvial ground water. Classic willow/alder development, common along southwestern streams, appears to be uncommon along Monument streams. Jacobs (1998) provided the following description of the canyon-bottom, vegetative community:

> Canyon bottom complex: a narrow riparian zone that includes overstory elements from the adjacent canyon slope along with floristic elements requiring enhanced moisture regimes. Some common species associated with this riparian zone include narrowleaf cottonwood, boxelder, mountain maple, gambel oak (tree form), alder (two species), beech, cherry and New Mexico Olive. Most of Bandelier's sensitive plants are associated with the perennial moisture found in the upper canyon areas. This is a fairly intact community in most areas where the historic use was limited to seasonal grazing. Exotic perennial grasses or invasive native shrubs can dominate areas developed for more intensive uses, such as Frijoles Canyon between Long House and the Stable (i.e. agriculture, housing, and, visitor use). Fire regimes for canyon bottom areas are comparable to the adjacent community. Desired future conditions for this complex are comparable to the adjacent community, but include reduction of exotic perennials and maintenance of existing hydrologic conditions necessary for current riparian vegetation.

Willow/alder communities are often dependent on recurrent disturbance regimes (i.e. some degree of shifting channel responding to bed and bank disturbing flood flows and flood plain inundation), which are normally lacking in Bandelier's smaller streams, probably as a result of dampened flood hydrographs.

Biological Resources

Fish

Bandelier contains several perennial stream reaches and perennial streams that typically harbor fish. However, no native fish species have ever been officially recorded for the streams within the boundaries of Bandelier National Monument (National Park Service, 1978; Platania, 1992; National Park Service, 1995a; Carter, 1997b). A number of native species (several extirpated) inhabited the Rio Grande and undoubtedly individuals utilized the perennial reach of Frijoles Creek below the lower falls. Other reports (Bandelier, 1890; Lummis, 1892; Willis, 1964; National Park Service, 1978) suggest Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis)* were once present in upper Frijoles Creek above the two lower falls. For example, both Lummis and Bandelier noted fish in Frijoles Creek, though species identification was not part of their description. The historic range of the Rio Grande cutthroat trout is not definitely known although it likely encompassed all waters presently capable of supporting trout in the Rio Grande drainage (Stumpff and Cooper, 1996). Fisheries biologists with the New Mexico

Department of Game and Fish note the regional occurrence of this subspecies in streams similar to Frijoles Creek and believe Rio Grande cutthroat trout were native to Frijoles Creek even above the barrier falls (National Park Service, 1978).

The Rio Grande cutthroat trout is New Mexico's state fish and was once widespread in the upper Rio Grande, Pecos, and Canadian River basins of northern New Mexico and south-central Colorado, possibly occurring as far south as Chihuahua, Mexico (Rinne, 1995). However, this subspecies of cutthroat has been in decline primarily as a result of hybridization and/or competition with exotic salmonids and habitat degradation. The current distribution of the Rio Grande cutthroat trout is estimated to be at 10 percent of its potential habitat (Stumpff and Cooper, 1996). The Rio Grande cutthroat is not federally listed as a threatened or endangered species; however, action is required to prevent the further deterioration of its status (Olson, 1985).

If Rio Grande cutthroat were native to Bandelier, introduction of rainbow *(Salmo gairdneri)*, brown *(Salmo trutta)*, and brook trout *(Salvelinus fontinalis)* would have rapidly eliminated it because rainbow trout readily hybridize (introgression) with cutthroat trout, in general, and brown and brook trout appear to be better competitors (Behnke, 1992). Fish stocking by the New Mexico Department of Game and Fish commenced in 1912 and continued until 1955. Their records show 36,750 brook trout, 82,740 rainbow trout, and 368,404 cutthroat trout of Yellowstone origin (species name not listed) were planted in Frijoles Creek during this time. Alamo Creek received 13,000 brook trout, 4,000 rainbow trout, and 6,000 Yellowstone cutthroat between 1919 and 1931, while Capulin Creek received 10,500 brook trout, 17,000 rainbow, and 1,500 Yellowstone cutthroat between 1922 and 1931. Undocumented introductions of brown trout have also occurred in these streams. Some of these nonnative trout species persist today with unknown impacts on the ecology of these streams and their rich aquatic invertebrate fauna (Allen, 1989a).

Anecdotal evidence and scientific opinion notwithstanding, whether the Rio Grande cutthroat trout is native to upper Frijoles Creek will never be resolved unequivocally; indeed, upper Frijoles may have lacked fish due to the barrier falls on lower Frijoles. In similar situations a weight-of-evidence approach is the best way to address zoogeographical dilemmas. Because of the occupation of Frijoles canyon by indigenous peoples, the presence of fish bones in archeological sites may provide additional, circumstantial evidence. In this case, the presence of trout-identified bones (only possible trout species would be Rio Grande cutthroat) would lend support to Rio Grande cutthroat trout being native to upper Frijoles.

Gehlbach and Miller (1961) identified fish bones from Rainbow House. This identification provided no additional evidence on behalf of the Rio Grande cutthroat trout; however, it is of zoogeographical interest. The bones belonged to that of the blue sucker (*Cycleptus elongatus*) the only representative of this monotypic genus.

At the present time, the blue sucker is not known to occur farther upstream in the Rio Grande than the vicinity of Big Bend National Park (Lee et al., 1980). The linkage of this species with

Rainbow House indicates that the blue sucker once occurred in the upper Rio Grande basin. It is doubtful that the indigenous people obtained the species at great distances from Rainbow House, and there is no indication that this species was used for anything other than food (Gehlbach and Miller, 1961).

The blue sucker engages in an annual spring migration (Gehlbach and Miller, 1961). The indigenous people of Rainbow House presumably caught this species as it ascended Frijoles Creek to the base of the lower falls. This barrier undoubtedly prevented farther upstream movement; however, fish may have been captured in the Rio Grande. Although the upper Rio Grande is not presently known to support the blue sucker (Koster, 1957; Lee et al., 1980), stream conditions during the occupation of Rainbow House were favorable. This suggests that the Rio Grande was a clearer, larger, and more stable stream than it is known to have been for more than a century.

Allen (pers. comm., Bandelier National Monument, 1999) summarized paleofaunal remains from local archeological sites. Besides the blue sucker, Rio Grande sucker (*Pantosteus plebius*), *Notropis* sp., *Pylodictus* sp. (probably flathead catfish), and "fish" have been recorded. The presence of *Pylodictus* sp. also suggests that the Rio Grande was cleaner, larger, and more stable than at present.

Allen (pers. comm., Bandelier National Monument, 1999) determined that Frijoles Creek went dry several times this century. Given the natural isolation of any native trout population by the two lower falls and the probability of local extinction in Frijoles Creek without adequate recolonization, chances are increased that extreme droughts or fire-induced floods in past millenia could have eliminated trout (and other members of the regional fish fauna that would be expected and which are currently absent) that may have been in the stream. Allen believes that regional patterns of native trout distribution may not be particularly relevant to the situation in Frijoles Creek.

Platania (1992) employed electrofishing techniques to collect fish samples from four sites within Bandelier National Monument: 1) Frijoles Creek just above its confluence with the Rio Grande; 2) Frijoles Creek near Monument headquarters; 3) Frijoles Creek headwaters; and, 4) Capulin Creek headwaters. One rainbow trout and two brook trout were collected at site 1, and 21 rainbow trout and 41 brown trout were collected from site 2; no other species were collected. No fish were collected from sites 3 and 4. Previous sampling information is unavailable for comparison to these results.

Only two fish species were collected from Frijoles Creek during USGS-National Ambient Water Quality Assessment (NAWQA) fish community sampling near Monument headquarters in 1994: 94 rainbow and 51 brook trout (Carter, 1997b). It is questionable that Carter found only brook trout and Platania (1992) found only brown trout associated with the rainbow trout in the headquarters reach of Frijoles. Either there was a dramatic shift in fish populations during the two-year interval separating their studies, or one of the authors mistakenly identified their catch. Fletcher (1990) while collecting fish samples to be analyzed for DDT contamination, found only brown and rainbow trout in Frijoles, and collected at least one brown trout from Capulin.

Of four sites sampled, Platania (1992) determined the most productive stream reach was near the Bandelier National Monument headquarters. The density of rainbow and brown trout in this reach was fairly high with sizes ranging from 2 to 10 inches and it is utilized to a limited extent by anglers (National Park Service, 1978). Two waterfalls on the lower Frijoles Creek appear to prevent the occurrence of the Rio Grande sucker (*Pantosteus plebeius)* or other regional natives in Frijoles.

Aquatic Macroinvertebrates

The first study of aquatic invertebrates in Bandelier was conducted on Frijoles Creek in 1978 after the La Mesa Fire (Pippin and Pippin, 1980). Unfortunately, the authors did not present their results in a manner that would allow quantitative community structure matrices to be calculated. A list was provided showing genera collected (by taxa but not quantified) at each of the four collection sites. A total of 107 benthic taxa were found, with the greatest diversity (73 taxa) occurring in the upper reaches above the burned section of the watershed. More genera were collected from the pollution/disturbance tolerant order Diptera (true flies) than any other. The ratio of pollution sensitive EPT (Ephemeroptera {mayfly}, Plecoptera {stonefly}, Trichoptera {caddisfly}) taxa to all taxa increased incrementally in the upstream direction. Interestingly, percent Diptera taxa also tended to increase in the upstream direction.

The most dramatic decreases in aquatic invertebrate numbers followed periods of heavy flooding resulting from the 1977 La Mesa fire. There was considerable damage noted in the stream channel below the burned area, and a corresponding decrease in the number (up to 98 percent reduction) and diversity of insect communities. However, above the area of major burning, flooding was not a factor that affected aquatic insect populations (Pippin and Pippin, 1980).

In a separate study, Pippin and Pippin (1981) studied the aquatic invertebrates of Capulin Creek. A total of 65 taxa were collected from Capulin. The reason so few taxa were found relative to Frijoles was the relatively short period of time devoted to the Capulin study and the fact that possibly more diverse headwater habitats are on U.S. Forest Service land and went unsampled. As in Frijoles, the dominant taxa in Capulin were of the Order Plecoptera, Trichoptera, Ephemeroptera, and Diptera. Diversity increased in the upstream direction, as did the EPT to all taxa ratio. In contrast to Frijoles, percent Diptera decreased in the upstream direction.

Stevens (1996) sampled macroinvertebrate communities above and below horse corrals near Frijoles Creek (headquarters area, following pollution control implementation) and Capulin Creek (Base Camp area), using full and rapid assessment techniques. While Stevens employed quantitative sampling and analysis methods, she did not produce numbers that could be readily compared to the earlier work of Pippin and Pippin (1980 and 1981). Stevens did not detect any difference in physicochemical or biological parameters in either stream resulting from the corrals. The major difference detected between the two streams was one of functional groups, with Frijoles being dominated by collector-gatherers and Capulin being dominated by scrapers.

Stevens also looked at a limited number of physical habitat parameters. Both streams contained relatively high amounts of fine substrate and subsequent embeddedness, leading to a reduction in the amount of overall high-quality, benthic macroinvertebrate habitat. The level of

embeddedness combined with low ionic content (particularly nutrients) and alkalinity in these streams may have contributed to the low overall abundance and diversity (Stevens, 1996).

Pippin and Pippin (1980) found two taxa in Frijoles Creek that they believed to be new to science, and two species of Plecoptera that were, at the time, new records for New Mexico. Black-light sampling for adult insects by Carter (1995) found four New Mexico records and one U. S. record for aquatic insects in Frijoles Canyon. Adult forms, because of their ability to fly, are not necessarily endemic to areas where they can be found.

MacRury (1997) is expanding on earlier macroinvertebrate studies by re-sampling both Frijoles and Capulin to determine the impacts of the Dome Fire on these communities and track their recovery. MacRury is collecting samples from a wide variety of sites and habitat types on both streams, and other streams draining the Pajarito Plateau, including Capulin's headwaters on U.S. Forest Service land.

Rare, Threatened, and Endangered Species

Potentially present federally listed threatened and endangered species include the bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco peregrinus*), whooping crane (*Grus americana*), Mexican spotted owl (*Strix occidentalis lucida*), and southwest willow flycatcher (*Empidonax traillii extimus*). Additional federal candidate and state-listed or otherwise sensitive animals found in the Bandelier area include: northern goshawk (*Accipiter gentilis*); ferruginous hawk (*Buteo regalis*); zone-tailed hawk (*Buteo albonotatus*); prairie falcon (*Falco mexicanus*); golden eagle (*Aquila chrysaetos*); gray vireo (*Vireo vicinior*); swift fox (*Vulpes velox*); and, Jemez Mountains salamander (*Plethodon neomexicanus*) (National Park Service, 1995a).

On August 19, 1994, the USFWS listed the Rio Grande silvery minnow (*Hybognathus amarus*) as an endangered species. Once occupying the reach of the Rio Grande adjacent to Bandelier and possibly utilizing the lower reach of Frijoles Creek, this species currently survives in only five percent of its historic range. The minnow's decline is attributed to river channelization, modified flow regimes, and the introduction of non-native predatory species (National Park Service, 1995a). Appendix C contains further information on protected and sensitive species occurring in the area (U.S. Department of Energy, 1998).

Ungulates

Elk (*Cervus elaphus*) remains have been found in low frequencies at local archaeological sites, possibly indicating the presence of only moderate elk populations from ca. 1150 to 1500 A.D. Rocky Mountain elk (*Cervus elaphus nelsoni*) were present in the Jemez Mountains into the late 19th century, but by 1909 all elk populations in New Mexico were considered extirpated. In 1948, the New Mexico Department of Game and Fish released 21 Rocky Mountain elk cows/calves and 7 bulls into the Jemez Mountains (National Park Service, 1995a).

The Jemez Mountain elk population exhibited exponential population growth over the past three decades. From the 1961 estimate of 200 animals, the population grew to an estimated 1989 level

of 6000 to 8000 individuals. The estimated annual growth rate for this herd is 13 percent, with a doubling time of 5.7 years. Elk were especially drawn to Bandelier after the 1977 La Mesa Fire, with winter use increasing from 100 animals in 1978 to around 1500 by 1992. The dramatic increase was due in part to the creation of about 14,820 acres of grassy winter range by the fire (Allen, 1996). Similar increases are expected in response to grassy range created by the 1996 Dome Fire.

Livestock grazing was officially discontinued at Bandelier when the NPS assumed control in 1932. At that time, "the whole area was heavily grazed," with 15 or more corrals, watering tanks, drift fences and other facilities to encourage grazing (Allen, 1989a). Trespass cattle continue to have access to the Rio Grande corridor and the lower reaches of Bandelier's canyons. Feral burros have also been a problem in the past but have been successfully eradicated. Large populations of mule deer (*Odocoileus hemionus*) within Bandelier may also be a management concern due to potential over-browsing.

Fire

Fire management is the single most important component of watershed management at Bandelier National Monument. As discussed previously, stream hydrographs undergo significant responses to widespread, intense, wildfires. The following passages from Neary (1995) describe watershed responses to wildfire in southwestern ecosystems:

> Fires affect the quantity of water derived from a watershed by reducing interception, storage, transpiration, and infiltration, and increasing overland flow, and surface storm flow. Watershed response to storm events is greater with shortened time to peak-flow and a greater susceptibility to flash floods. Flood-warning times are also reduced by "flashy" flow and higher flood levels can be devastating to property and human life.
>
> Total water yields from burned watersheds are higher, especially in areas where the majority of precipitation is derived from rainfall and the evapotranspiration rate is high. The magnitude of measured water yield increases the first year after the fire disturbance and can vary greatly at one location or between locations depending on the fire intensity, climate, precipitation, geology, soils, watershed aspect, tree species, and proportion of the forest vegetation burned. Watershed recovery can vary from a few years to decades.
>
> Factors that increase erosion in wildfire settings are the increased overland and peak flows, fire-line construction, temporary roads, and watershed rehabilitation activities. Soil and sediment loss can take the form of sheet, rill, gully, or stream bank erosion. Fire associated debris avalanches are a form of mass wasting that delivers sediment directly to streams in large quantities.
>
> Wildfires generally produce higher sediment yields than other forest disturbances. After fires, turbidity can increase due to the suspension of ash and soil particles. The increased erosion and peak flows can also increase bed loads, which can destroy stream habitat.

Wildfires can also interrupt uptake of anions and cations by vegetation and speed up mineral weathering, element mineralization, microbial activity, nitrification, and decomposition. These processes result in the increased concentration of inorganic ions in the soil solution and leaching to streams via subsurface flow.

Ammonium-based fire retardant can produce short-term mortality in some aquatic organisms. Non-ionized ammonia is the principal toxic component to aquatic species. Impacts from toxic ammonia levels depend on stream volume, the amount of retardant dropped, and the orientation of the drops to the streams long-axis.

Wildfires can also increase stream temperatures by removal of shade and the direct heating of water surfaces. This can result in decreased dissolved oxygen concentrations and increased plant growth. The above mentioned disturbances resulting from wildfire ultimately cause cumulative impacts on aquatic biota, the longest lasting of which is in-stream habitat degradation.

As with most federally managed natural areas, the importance of fire to Bandelier's ecosystems and watersheds was unrecognized until the 1970s. Fire suppression dominated most of the past century, in direct contrast to the fact that the Monument's plant communities are mainly fire-dependent (Allen 1989a; Touchan and Swetnam, 1992; Touchan et al., 1996).

In a detailed study of fire histories, Allen (1989a) found that prior to the 1890s small fires burned through the ponderosa forests of the Pajarito Plateau about every 5 to 15 years. The mean fire interval in the Frijoles watershed was 11.6 years based on analysis of tree-rings spanning the years 1598-1893. This value is consistent with other fire histories determined for ponderosa pine and mixed conifer vegetation types. The mean recurrence interval for widespread fires (basically watershed-wide) was approximately 25 years. Only one possibly watershed-wide fire occurred after 1851. The sharp drop in fire frequency was apparently caused by the introduction of sheep and cattle to the area in the late 1800s, with the resultant loss of the grassy ground cover that had previously allowed lightning-caused fires to spread. Allen concludes that grazing and fire suppression converted former, low-intensity, high-frequency fire regimes into high-intensity, low frequency fires (Allen, 1989a).

Fuel loading, vegetation conversion, and related factors associated with poor fire management erupted in 1977 and 1996 as the La Mesa and Dome wildfires burned out of control. The 1977 La Mesa fire burned 15,000 acres, including roughly one-third of the Monument; while the 1996 Dome Fire burned over 16,516 acres in Bandelier National Monument and the adjacent Santa Fe National Forest. These were the most widespread fires to occur in the watershed since at least 1899, and both were predominantly intense crown fires consuming dense thickets of ponderosa pine (Allen, 1989a; Reneau et al., 1996b). The fires burned a total of 27,615 acres, or almost 60 percent of the Monument's watersheds (Figure 22).

In these intense, large-scale wildfires, vegetation and forest-litter were scorched from the forest floor. Given these conditions, resin content and organic litter can be volatilized, subsequently condensing on mineral soil particles to produce an extremely water repellent, or hydrophobic layer. Tests following the Dome Fire revealed only extremely localized development of

hydrophobic soils (Cannon, 1997). Other field studies attributed loss of infiltration capacity to the development of a thick and extensive layer of ash (Reneau et al., 1996b; White and Wells, 1984).

In both Frijoles and Capulin canyons, a series of damaging flash floods occurred during the three summer monsoon seasons following the fires. Riparian systems sustained direct and indirect impacts associated with alteration of stream channels, banks, and flood plains. Wholesale loss of riparian plants occurred in some cases either by erosion or sedimentation (burial). The pre-fire stream channel was variably down-cut many feet to bedrock, significantly widened, and/or banks were undercut. Large rocks and boulders were transported and deposited in clusters, establishing new stream morphologies. In some instances, entirely new channel sections replaced the old ones, either through abandonment or sedimentation (National Park Service, 1996a).

Preliminary assessments of the Capulin aquatic system by Stevens (1996) suggest the aquatic invertebrate and water chemistry parameters were significantly altered from pre-fire conditions (National Park Service, 1996a). Water chemistry was also affected and both Purtymun and Adams (1980), and MacRury (1997) noted a three- to four-fold increase in the transport of base cations and anions. In Frijoles, a macroinvertebrate reduction of 98 percent was experienced after heavy flooding following the La Mesa fire (Pippin and Pippin, 1980). In addition to the immediate impacts, stream habitat quality was severely impaired and sediment input has increased embeddedness that has been linked to reduced macroinvertebrate density and diversity in Frijoles long after the La Mesa Fire.

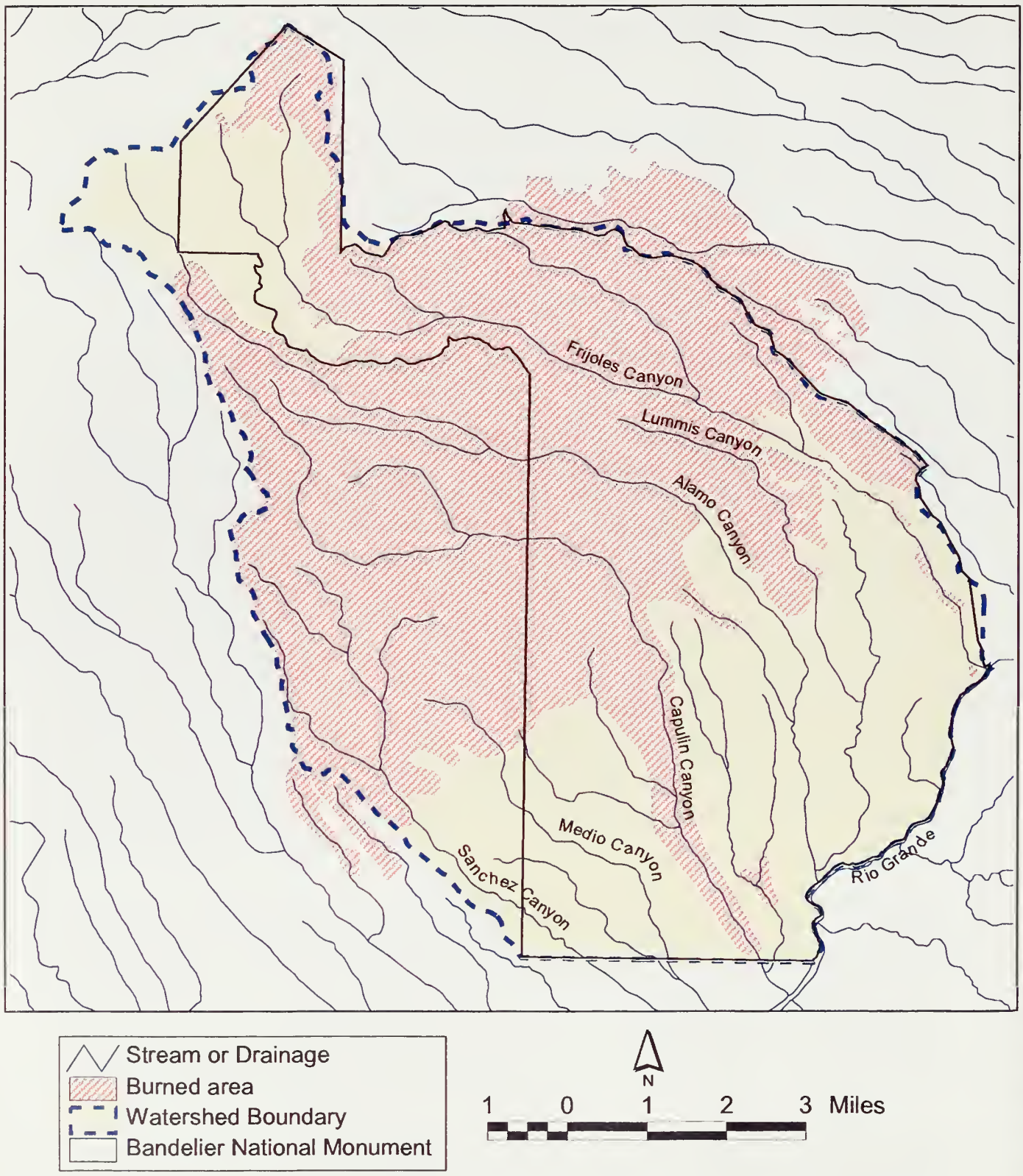

Figure 22. Wildfire Distribution in Bandelier National Monument. (Source: BAND-GIS)

Fluvial Geomorphology

The following discussion focuses on the physical condition of Bandelier's streams. Maintenance of natural physical processes is perhaps the most fundamental component of ecosystem management. The community of organisms inhabiting a stream reach has developed over thousands of years, and changes in physical habitat condition and/or distribution will alter these communities, often over large temporal and spatial scales.

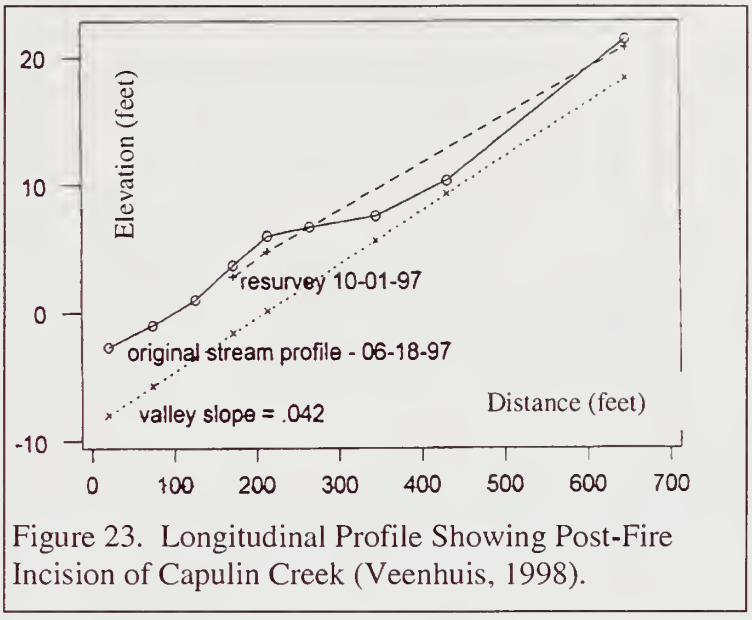

Figure 23. Longitudinal Profile Showing Post-Fire Incision of Capulin Creek (Veenhuis, 1998).

Even a casual observer can perceive the annihilation of habitat (i.e. pools, riffles, and runs) within Capulin Creek as a result of the floods triggered by the Dome Fire. The most obvious physical alteration is entrenchment which results in the stream channel being down-cut and widened so that subsequent flood flows are confined to a vertically walled trench and no longer spread out upon adjacent flood plains. The process of regaining a stable channel type is impeded by the inability of post-fire bank-full discharges to redistribute the available bedload and form a stable channel cross-section and new flood plain. Close scrutiny of geomorphic parameters in Frijoles reveals physical habitat alterations still exist in some of its reaches 20 years after the La Mesa Fire.

Figure 23 shows the response of a portion of the Capulin channel to Dome Fire induced flooding. Incision in the reach adjacent to Capulin Base Camp was as great as 4.7 feet. Maximum incision observed by the author further upstream was estimated to exceed 8 feet (Photo 1 and 2). In other reaches, cobbles and boulders excavated by the floods were re-deposited, burying the pre-existing channel. A striking example of channel response to post-fire flows is shown in Figure 24 and Photo 3. The gauge and flume labeled in Figure 24 can be seen near the center of Photo 3. The flume and gauge were installed in 1985 and passed all flow (except one event in 1988 which overtopped the concrete flume but was less than the elevation of the chart recorder) and sediment until 1996. According to Veenhuis (1998) "During the initial inspection on June 13, 1996, this flume was to be re-instrumented to monitor post-fire runoff, but on June 26, 1996 when the first and largest post-fire flood occurred (2,700 cfs), the flume was inundated with large boulders and debris. Thereafter the stream cut a channel on the right side of the flume wall and began down cutting and widening the channel to accommodate the larger flows." The new channel cross-section is also plotted in Figure 24 and can be seen to the right of the old flume in Photo 3.

Another significant aspect of the incision was the removal of the cobble and boulder armor from the streambed and exposure and incision into the underlying friable sandstone. This easily erodible bedrock is visible in Photo 2 as the white strata rising about 6 feet above the level of the

Photo 1. Stream Channel Incision within Capulin Canyon.

Photo 2. Channel Incision and Potential Slope Destabilization in Capulin Canyon.

Photo 3. Peak-Flow Gauging Flume and Post-Flood Channel Within Capulin Canyon.

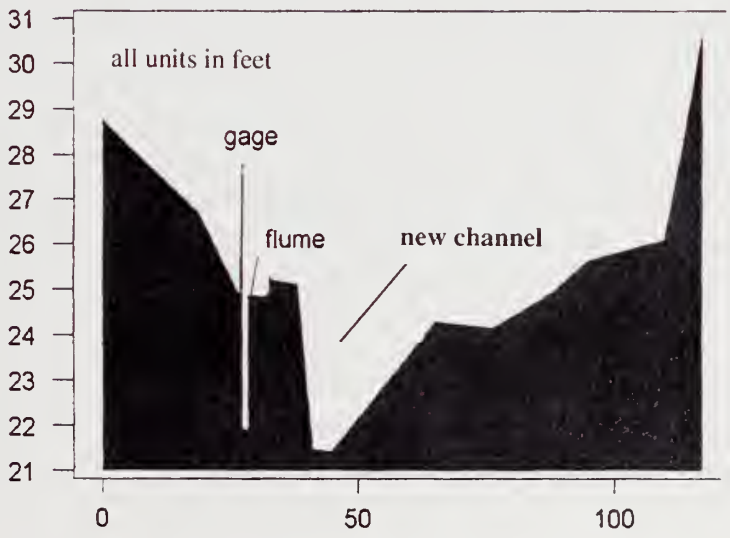

Figure 24. Post-Fire Cross-section of Capulin Creek at Old, Peak-Flow Gauge (Veenhuis, 1998).

stream. Incision into this unit might be providing a modern analog for processes leading to formation of terraces observed in many Pajarito Plateau Canyons (Reneau et al., 1996b). Because the intensities of both the Dome and La Mesa fires are believed to be unprecedented in the several-hundred-year long fire record on the Pajarito Plateau, it is possible that the resultant fluvial geomorphic effects are also unprecedented. While historic records show little in the way of large-magnitude floods outside of post-fire years, field evidence indicates catastrophic flooding has taken place in pre-historic times (Reneau et al., 1996b).

Stratigraphic relations and radiocarbon dating indicate that mid- to late-Holocene (within the last 5,000 years) sediments in many canyons recorded repeated episodes of alternating channel aggradation or stability and channel incision, with incision being dominant at an average rate of 4 mm/year (Reneau et al., 1996a). It is notable that there is abundant evidence for significantly larger floods on the floor of Capulin Canyon, including extensive boulder deposits commonly containing boulders much larger than those transported by recent floods (2,700 cfs). Their presence indicates the potential for significantly larger floods (Reneau, 1996). Depending on the interpretation of the base level of the channel bottom at the time of pre-historic flooding, flow reconstruction estimated a flood magnitude between 9,000 and 10,500 cfs. The cause of these earlier flood peaks is unknown (Veenhuis, 1998).

McCord (1996) examined flood-scars on trees and radiocarbon dates from sediments to reconstruct a record of past flood events on Frijoles Creek. The scar dates ranged in age from 1773 to 1985, with most of the scar dates falling in 1977 and 1978. McCord determined there have been at least four floods comparable to the 1978 flood (greater than 3,000 cfs) in the last two centuries, and at least seven floods as large as the flood of 1977 (653 cfs) during that time. Other than the 1977 scar, only the 1773 flood scar matches a major fire year in the local fire scar record. This suggests one of two possibilities: that fire intensity, rather than fire extensiveness, is the major factor leading to post-fire flooding; or, the occurrence of floods in Frijoles Canyon can be independent of fire (McCord, 1996).

Other potential sources of damaging floods are rain on snow or other anomalous precipitation events; landslides; and, debris flows. Cannon et al., (1998) determined debris-flow and landslide susceptibility in Capulin Canyon was low, but the potential for debris-flow was observed in two tributary canyons. Another potential scenario that could result in catastrophic flooding is an outwash event. As an example, the slope above Capulin Creek shown in Photo 2 has been destabilized by channel incision, and could become further destabilized as the friable sandstone is laterally eroded from the toe of this slope. If slumping occurred during a high-water event, the water could be dammed behind the slump and released as an outbreak event when the slump was overtopped, undermined, or circumvented. According to Allen (1989a), landslides in the Jemez Mountains occur mainly on steep slopes within canyons. In the Frijoles watershed, a landslide occurred below the lower falls in 1942, destroying about 150 yards of trail. At least three other notable rock-slides/landslides have occurred in the Frijoles watershed since that time (Allen, 1989a).

Staffing and Ongoing Programs

National Park Service managers at Bandelier have assembled a very competent resource staff who has developed sophisticated projects and programs. The organization of the Resource Management Section is shown in Figure 25. Charisse Sydoriak has been the Chief of this section since 1991. While none of these staff positions is dedicated to water resource management, many of the administered programs directly or indirectly benefit water resources.

Brian Jacobs, Vegetation Specialist, is responsible for most aspects of water-related management, such as research and project oversight, and maintenance of the stream gauging station on Frijoles. Brian has developed watershed-scale vegetation restoration projects, and was the principal contact for the development of this plan. Dr. Craig Allen, with the U. S. Geological Survey, Biological Resources Division, is stationed at Bandelier and is involved with Cochiti Reservoir issues and helps coordinate an Interagency Biological Working Group striving to enhance reservoir management for the benefit of wildlife and other natural resources. Dr. Allen is also involved with landscape level vegetation and erosion monitoring and mitigation, along with other issues pertinent to resource management. Stephen Fettig is Bandelier's Wildlife Biologist and is currently involved with a major elk study and represents Bandelier on the Interagency Biological Working Group.

Recent and ongoing water resource research and projects include:

- Water quality, discharge, and benthic macroinvertebrate data were collected from the Frijoles and Capulin watersheds for two years (Stevens, 1996) prior to the outbreak of the Dome Fire. Ongoing research (MacRury, 1997; National Park Service, 1996a) is designed to examine the effects of a large-scale disturbance (fire) on an aquatic ecosystem. Changes in stream hydrology, water chemistry, and benthic macroinvertebrate communities in Capulin will be compared before and after the fire, and with the adjacent unburned Frijoles watershed, utilizing data and experimental studies conducted over a 3-year period.

- A USGS - NAWQA, fixed site was established on Frijoles Creek and collected stream flow, water chemistry (including trace elements), organic pesticide levels (in fish, aquatic invertebrates, and bed sediments) and ecological surveys of stream and riparian habitat and benthic, algae, and vascular plant communities. The site was active from 1993 to 1996.

- The NPS Water Resource Division recently completed a *Baseline Water Quality Data Inventory and Analysis* report for Bandelier National Monument (National Park Service, 1997). The report inventoried the Monument's water quality data, establishes baseline water quality, identifies water quality impairment, and synthesized a comprehensive and accessible database.

- Los Alamos National Lab (LANL) continues to collect a broad range of water quality baseline data at the Frijoles gauge site for its annual perimeter surveillance efforts (radiochemical analysis is sometimes included). Sediments are occasionally monitored within the wetland area at the head of Cochiti Reservoir. A massive, multi-million dollar

Figure 25. Organization Chart for Resource Management Section.

ground water assessment program is currently being implemented by LANL and its contractors.

- The New Mexico Environmental Department entered into an agreement with the U.S. Department of Energy in October 1990 to provide guidance regarding applicable state environmental laws and regulations. These include air quality, surface and ground water quality, and hazardous and radioactive materials issues. In January 1995 a separate NMED bureau (LANL/DOE Oversight Bureau) was created to handle these functions. Oversight of LANL is provided by a staff of seven based in White Rock, supplemented as necessary through a technical support staff based in Santa Fe and Albuquerque (Stone, 1996).

- Bandelier is working through the NPS, Geological Resources Division to fund geologic field work under the Geologist in the Parks Program. Steve Reneau, a geologist with Los Alamos National Laboratory, is assisting with technical guidance. The project will help ongoing paleo-geographic re-constructions that are being performed to address concerns related to perched water and contaminant movement down the troughs of paleo-valleys.

- Staff with the USGS has been involved with hydrologic monitoring of Capulin Creek and its watershed. The main purpose of these studies is to quantify post-fire peak flows for comparison with pre-fire flows, quantify gross channel responses to floods, assess the potential for debris flows and landslides in Capulin and its tributary canyons, and assess the potential flood hazards posed to visitors and Monument personnel.

- Ongoing prescribed fire and vegetation restoration programs should also have positive affects on water resources as discussed in the issues section. A major elk research project is also underway to determine such things as density, distribution, and impacts on native vegetation.

WATER RESOURCE ISSUES AND RECOMMENDATIONS

Watershed Management

Stream stability, aquatic habitat integrity, and watershed condition are interdependent. Streams draining a landscape are stable (naturally functioning) when the water and sediment delivery is balanced with the stream's ability to assimilate and transport these loads. Inputs of water and/or sediment that exceed the stream's assimilative/transport capacity will result in channel destabilization, as has been observed at Bandelier. Stream destabilization negatively impacts aquatic and riparian habitat, disrupting natural communities for long periods of time and over extensive stream lengths. This section discusses two issues that must be considered at the watershed scale: stream response to wildfires; and landscape-scale erosion.

Fire Management

Hydrologic responses to wildfires (peak flow, sedimentation rate, etc.) are mainly a function of both fire severity and climactic events following the fire, along with such factors as topography, soils, vegetation structure, stream size and morphology and others (DeBano et al., 1995). Prescribed fire usually has minor hydrologic impacts on watersheds because the surface vegetation, litter, and forest floor are only partially burned. During some wildfires, where the temperatures, wind speeds, and fuel loading are high, and the humidity and fuel moisture are low, profound effects can be manifested on basic hydrologic processes. This can be especially pronounced in ponderosa pine forests where under natural fire regimes or prescribed fires, usually the litter and smaller diameter surface fuels are ignited; as compared to near total canopy consumption during intense wildfire (DeBano et al., 1995).

Intense, widespread wildfires have triggered two major episodes of stream "blowouts" at Bandelier since 1977. These recurrent, high-magnitude flood periods stand in sharp contrast to decades of preceding- and post-fire quiescence. Documented biological impacts from damaging post-fire floods include a 98 percent reduction of aquatic insects in Frijoles Creek following the La Mesa Fire (Pippin and Pippin, 1980), and dramatic reductions in abundance and biodiversity of benthic macroinvertebrates in Capulin Creek following the Dome Fire (MacRury, 1997). Non-quantified but documented reductions in fish numbers, and loss of riparian vegetation have also been observed.

One benefit of these wildfires is that the inevitable has happened. Nearly a century of unnatural plant succession and fuel loading was derailed over the majority (60 percent) of the Monument's watersheds (Figure 22). Allen (pers. comm., Bandelier National Monument, 1998) believes the headwaters of Frijoles represents the only substantial area where intense crown fires could yet occur. The lower unburned elevations shown in Figure 22 are composed of piñon-juniper communities that do not support surface fire in their current state, but may in the future under extreme drought or high wind conditions.

Recommendation: Long-term preservation of watershed functioning must begin with restoration of natural vegetative communities and associated fire regimes. Watershed functioning, vegetative communities, and fire regimes are inseparable elements in the majority of Bandelier's

environs. Restoration of fire-dependent plant communities and natural fire recurrence intervals will, in turn, maintain associated soil structures and infiltration capacities. Vegetation, soil, and infiltration maintenance are the key elements of a properly functioning watershed, one in which water and sediment delivery is in balance with stream assimilation and transport.

The staff at Bandelier is aware of the need for landscape scale vegetation and fire restoration, and is actively pursuing these goals on a unified front. More importantly, Bandelier's knowledgeable, aggressive, and competent staff (Figure 24) have the tools and support to effect change at the landscape level. However, the fuel loading and change in forest structure at higher elevations has created a hazardous condition that will be very hard to correct even with competent staff and modern fire management techniques.

As prescribed fire is further implemented, stream monitoring should be performed/continued to determine the relative impact of prescribed fires on flow, stream habitat, and biological resources. The fires must also be structured to assist recovery of vegetative communities, as best determined by the staff at Bandelier. Fires should be initiated at an interval, size, and intensity that most closely matches the pre-European settlement fire history. Some stream response to prescribed fire is expected, the magnitude of which should represent natural fluxes. A proposal has been developed which describes specific monitoring procedures to determine the relative impacts of prescribed fire on the Monuments hydrology.

The most applicable monitoring tools are:

PARAMETER	DESCRIPTION OF USE
Flow	A sensitive parameter responding dramatically to previous wildfires. Smaller responses to prescribed fire are therefore expected. Peak flows resulting from prescribed fires should be kept below levels that negatively impact habitat or biological communities.
Water Quality	Previous studies have shown changes in base anion and cation concentrations following wildfires. Specific conductance and pH will therefore be monitored to assess statistically significant changes in dissolved ions. Water temperature and dissolved oxygen will also be measured because of their relation to potential increases in sunlight and nutrients. Turbidity will be measured to assess potential increases in suspended solids, and fecal coliform samples will be collected at the gauged monitoring station because this represents a valuable opportunity to assess backcountry water quality as influenced by visitor activities.
Physical Habitat	Before and after measurements of embeddedness, substrate composition, bankfull width, and entrenchment will be performed to determine if potential changes in flow regimes are sufficient to cause stream channel responses. Cross sections will be established for before and after surveying. Results should correlate with flow and biological communities.
Biological	Rapid bioassessment techniques will be employed utilizing macroinvertebrate collections. Results should correlate with flow, physical habitats, and water quality, and determine if changes in any of the above mentioned parameters are causing changes in biological communities.

See Appendix D for Fire associated project statement

Erosion Management

Elevated rates of watershed erosion deliver excess amounts of sediment to streams. At least one-third of the Monument (piñon-juniper woodland) exhibits chronic excess soil loss. During post-wildfire periods, the area of the Monument producing high sediment loads increases. Sediment delivery is an important consideration at Bandelier because natural stream hydrographs typically

lack large "flushing flows" which would more effectively transport sediments. This factor also contributes to the high amount of embeddedness noted in Monument streams (Stevens, 1996). Fortunately, the piñon-juniper zone lies at lower elevations (Figure 4), and sediments derived from this area mainly affect the lower reaches of Bandelier's streams, with only Frijoles Creek being perennial in its lower reach. Sydoriak (pers. comm., Bandelier National Monument, 1998) stated that Capulin Creek may also be maintaining perennial flow in its lower reach after the Dome Fire.

Studies indicate that some piñon-juniper subwatersheds could lose all soil in the coming century (Allen, 1989a; Earth Environmental Consultants, 1978; and National Park Service, 1995b). Denudation would effectively generate areas of "slick-rock" country and dramatically change the infiltration characteristics of the watershed. Decreased infiltration capacity will increase the volume of storm runoff delivered to stream channels.

Other sources of sediment include trails, unpaved road surfaces, and road ditches within and upstream of the Monument. Roads and trails have the effect of extending an area's drainage network, allowing sediment laden storm flow to be delivered to streams more efficiently. Streambanks with decreased vegetative cover or bare soil produce sediment directly to the stream. Increased ungulate populations could also increase sediment yield in the higher elevations of the watershed by reducing vegetation, increasing soil compaction, and causing trail and gully development.

Results from ongoing experimental restoration work at Bandelier are encouraging and suggest recovery of degraded piñon-juniper woodlands is possible through the application of a coordinated woody overstory thinning/slash mulching treatment. Implementation of this restoration treatment, at multiple scales, has produced compelling results relative to both pre-treatment condition and to controls; large decreases in exposed soil area and significant increases in litter and herbaceous coverage have been observed (National Park Service, 1995b).

Recommendation: Bandelier's staff recognizes the importance of mitigating soil erosion because of the damage it is causing to cultural and natural resources. More importantly, they are actively pursuing landscape-scale monitoring and restoration programs that focus on restoring vegetative communities. Leopold (1994) has studied hydrologic responses of southwestern streams to structural mitigation attempts (such as check dams), and has stated that restoration of plant communities is the most feasible long-term solution to erosion. Landscape-scale restoration is a complex, labor-intensive, long-term process. However, it is Bandelier's top-priority resource management goal, with a vegetative specialist and ecologist devoting much of their time to this effort. It is recommended that these efforts continue under the knowledge that stream processes and communities will benefit from these efforts as well.

Bandelier has approximately 75 miles of maintained trails, including moderate to steep grades and switchbacks. While it was observed that most of the trail system was adequately maintained, numerous stretches of eroding trail exist, along with erosion below trails where water is routed into discrete side-slope areas. This situation could be improved by renovating the trails so that they have a positive slope. It is recommended that trail surfaces dip a few degrees in the down-slope direction, allowing water to flow across the trail instead of down it. Increasing the density

of water diversions could be used where positive slope construction is unfeasible. Water diversions should also drain into low-slope receiving areas wherever possible. Routing water directly across the trail surface has the added benefit of preserving moisture delivery below the trail, which benefits vegetation in these areas.

Similar construction recommendations are made for roads, especially in light of their larger and more impervious surfaces. As opposed to the use of water bars, additional ditch turnouts and culverts should be installed where erosion of the ditch or receiving area is noted. Turnouts and culverts should also be designed to drain to low-slope areas wherever possible. Additionally, transfer of headwater areas from USFS to NPS ownership could allow a road system evaluation to be conducted in this area, possibly reducing the density of the road network and allowing restoration of abandoned roads. Bandelier's headwaters contain more than 200 miles of abandoned roads (Allen, 1989a).

Streambank erosion caused by reduced riparian vegetation or exposed soil was observed mainly in the headquarters reach of Frijoles Creek and will be discussed under the infrastructure section. Overgrazing by ungulates (mainly elk) is also a recognized concern of Bandelier's management, and studies of their numbers, behavior, and impacts on vegetative communities are currently underway.

Infrastructure

The National Park Service maintains a large number of structures and facilities within the canyon, on the flood plain, and across the channel of Frijoles Creek. Within the canyon, these include concessions (restaurant and gift shop) operations, maintenance facility, administrative and support offices, visitor center, access road, and employee housing. Below the elevation of the mapped 100-year flood plain are picnic area restrooms, picnic area and visitor center parking, and sewer lines. Below the mapped 500-year flood plain lays the visitor center, maintenance offices, wood/welding shop, oil house, lumber storage, search and rescue cache, and fire cache. Across the Frijoles channel is one road-bridge and several pedestrian bridges. The foundation walls of an older bridge remain on both sides of the stream, and a horse ford crosses the lower headquarters reach. Unlined pit toilets were also in use near Frijoles Creek at Ceremonial Cave just upstream from the headquarters operation, but are being replaced with vault toilets in 1999. Much of this infrastructure is historic Civilian Conservation Corps work.

Infrastructure development within units of the National Park Service is arguably at odds with the Organic Act. To promote intensive visitor access in discrete areas has the potential to degrade the resources the National Park Service was mandated to leave unimpaired for the enjoyment of future generations. Development within the flood plain risks infrastructure damage and visitor and employee safety. Increased storm runoff, sedimentation, hard-structures, and direct trampling of the stream channel can also degrade stream habitat. The generation, transport and disposal of associated sewage have the potential to spill or leak into receiving surface or ground water. Maintenance operations, parking surfaces, and household, office, and yard chemicals are a potential source of hazardous materials that arrive at receiving streams by both point and nonpoint transfer mechanisms (e.g. DDT and maintenance yard contaminants in Frijoles Creek).

Visitor Access

Recreational use of riparian areas throughout the nation is increasing, particularly in the southwest. At the same time, high quality riparian and stream channel habitat along perennial streams in New Mexico is a resource in decline. For example, U.S. Geological Survey physical habitat and geomorphic measurements conducted as part of the NAWQA Program in the Rio Grande Basin determined that the 300 feet reach of Frijoles Creek below the stream gauge was the only site (out of 10) that had minimal habitat degradation. The habitat at Frijoles Creek was characterized by no stream modification, very little bank erosion, highly stable banks, and dense riparian vegetation (Levings et al., 1998).

Bandelier receives about 420,000 visitors each year. The majority of these visitors utilize the information center, picnic area, and cultural ruins near the Monument Headquarters in Frijoles Canyon. Of specific concern is the picnic area. The picnic area comprises a linear band of pull-offs and picnic tables along approximately 1,400 feet of the south bank of Frijoles Creek. Running water attracts children, who romp and play in the creek, build small dams, throw rocks, slide down the banks, and grab vegetation to climb back up the bank. On any given day, damage to the stream and streamside vegetation is minimal, but over the course of years, the accumulated impacts have measurably altered this reach of stream.

As part of the field investigation associated with developing this plan, a rapid physical assessment was performed near the headquarters. The purpose was to quantify, at least at a rudimentary level, observable alterations to the stream reach at the picnic area, as compared to upstream and downstream reaches. The assessment began with an estimation of the bankfull stage as interpreted from the headquarters gauge and field observations. Parameters measured included bankfull width, flood-prone area, average bankfull depth, substrate size, and embeddedness (Appendix A). Percent vegetative cover was also estimated for both banks. Rosgen's (1996) definition of stream entrenchment was also calculated along with the bankfull area. The study reach began 25 feet upstream from the horse crossing, and measurements were recorded at 50 feet intervals in the upstream direction for a distance of 3,150 feet. The last measured cross-section was 400 feet above the picnic area.

A detailed classification of stream type according to Rosgen (1996) was not possible given the limited amount of geomorphic parameters collected. However, estimation of water surface slope and channel sinuosity reveal that this stream reach is near the cutoff between the B (summarized as fast flowing and constrained) and C (pool/riffle and meandering) stream types. Gravel and lesser amounts of cobble and fines typically dominate the substrate. Limited intervals are dominated by cobble, and other intervals show exposed bedrock (basalt). Figure 26a shows the character and relationship of bankfull width, substrate size and vegetative cover throughout the surveyed reach. Figure 26b shows the same data using a five-point moving average that allows the general trends to be more easily interpreted.

These data show that direct trampling of stream banks has caused a reduction of vegetative cover from near 100 percent above and below the affected reach to an average of 20 to 30 percent within the affected reach (many intervals of completely bare banks were observed). Average bankfull width is 75 percent (from 7.25 to 10.6 feet) to 83 percent (from 6.5 to 10.6 feet) greater

than upstream and downstream reaches, respectively. Maximum bankfull widths observed above and below the degraded reach were 10.3 and 10.0 feet, respectively, while along the picnic area the maximum bankfull width was 18.8 feet. Narrow stream reaches, due to their inherent higher velocities, are more efficient at transporting bed (particles bounced along on the stream bottom) and suspended loads.

Also shown in Figures 26a and b is the average sediment size below the bankfull stage. Within the reach showing reduced vegetative cover and increased bankfull width, the average substrate size decreases, and fine particles (mud and sand) become increasingly common. In correlation with the decreased substrate size was a tendency toward increasing embeddedness. In many intervals within the degraded reach, fines completely covered the substrate, which was never observed above or below. Increased abundance of fines decreases habitat diversity. Reduced habitat values can take many forms, including filling of pools, reduction of pool volume, increased shallow runs, loss of cobble and gravel substrate which provides cover from predators, spawning areas, and protection from flooding, and shifting substrate which increases turbidity and decreases periphyton (attached aquatic plant) production. Because habitat value is diminished, aquatic communities typically show reduced biological diversity and a shift toward more tolerant species in geomorphically degraded reaches.

A final observation from the rapid physical assessment data is the significant increase in the number of cross-sections categorized as entrenched in the vicinity of the picnic area. An entrenched stream reach no longer has access to its flood plain, and is often indicative of past or ongoing degradation, either at the local or watershed scale (Rosgen, 1996). In this case, the upstream and downstream reaches are not entrenched, which indicates degradation on a local scale. It should be noted that cross-sections measured by Veenhuis (1998, example in Figure 24) on Capulin Creek show this stream to be entrenched as a result of post-fire flooding and associated channel degradation. Physical descriptions of the Frijoles channel following the La Mesa fire indicate a similar degraded and entrenched stream state throughout many reaches (White and Wells, 1984; White, 1996).

Natural sediment transport and deposition processes will allow entrenched streams to redevelop flood plains within the over-widened and often down cut channels. This flood plain rebuilding process appears to have been effective above and below the picnic area over the twenty years since the La Mesa fire. However, the reach near the picnic grounds remains mostly entrenched. From this it can be inferred that the stream reach adjacent to the picnic area never recovered from the post-fire flooding, and that the lack of recovery is a result of recurrent trampling and loss of stabilizing vegetation.

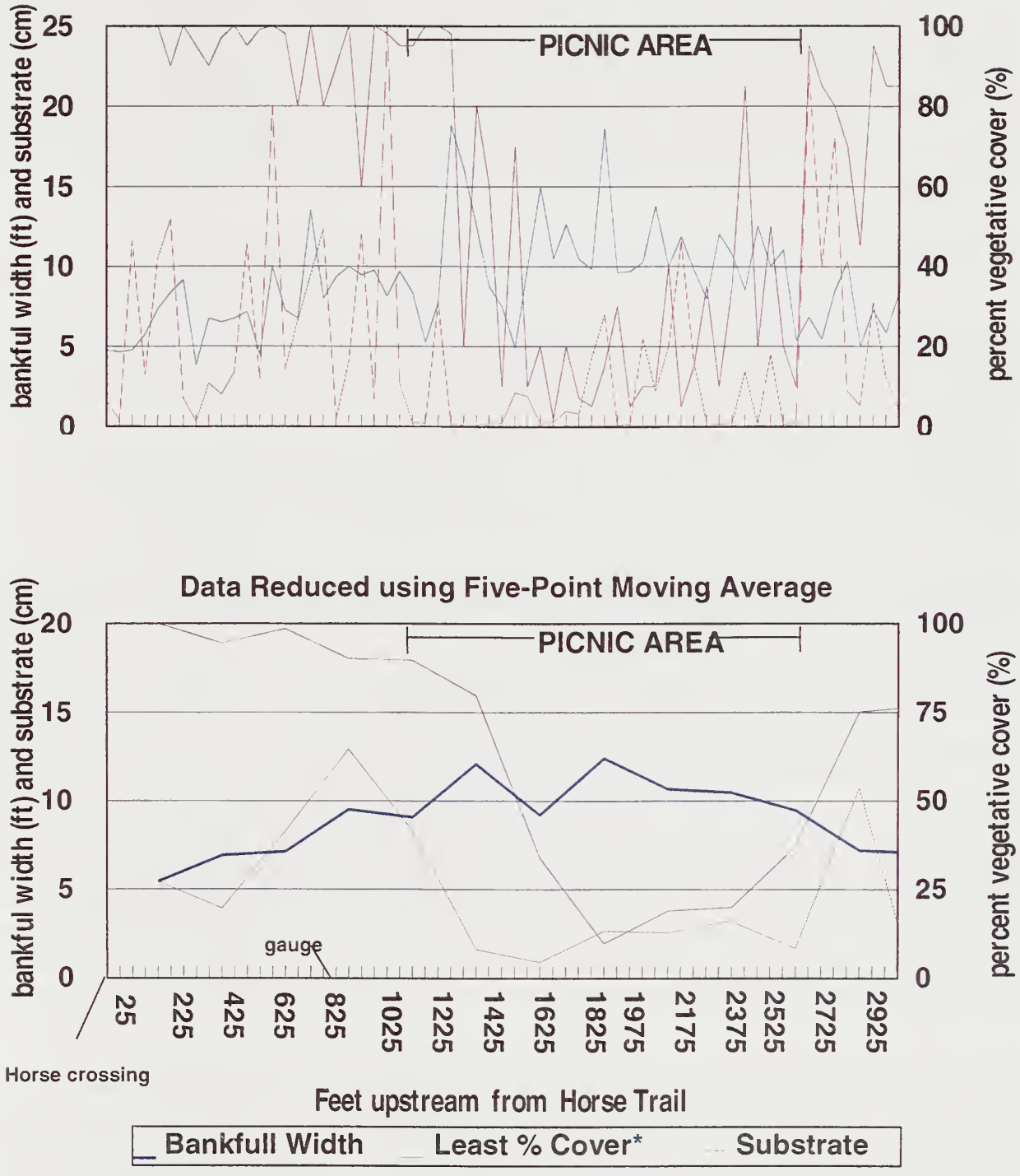

Figure 26. Top (a) Rapid Physical Assessment Results for Headquarters Reach on Frijoles Creek; Bottom (b) Five Point Moving Average.

Recommendation: Restoration of the headquarters reach of Frijoles Creek will require controlling visitor impacts to the stream and streamside. The watershed of Frijoles Creek is almost entirely wilderness and backcountry, and natural hydrologic conditions currently prevail upstream of the disturbed reach. This means that flow and sediment transport are also at natural levels, and watershed disturbance is not a contributing factor to the degraded reach of stream near the headquarters. The impacts to Frijoles Creek are both local and chronic in nature, and restoration hinges on one principle component, elimination of abusive levels of human traffic. The second recognized need in the disturbed area is revegetation. When exclusion and revegetation measures are implemented, natural processes will allow the stream channel to recover within a few years.

The recommended work to accomplish exclusion, revegetation, and recovery is:

1) Build a fence along both sides of the disturbed stream reach and route traffic from the picnic area to the headquarters facilities across existing bridges.
2) Spread slash over de-vegetated areas to encourage re-growth of native vegetation and further discourage visitor access.
3) Hire seasonal employee to contact visitors crossing into the restoration area and ask them to honor the fence. Seasonal employee will also monitor reaches above and below the fenced portion of the stream to insure stream disturbance is not transferred to other reaches.
4) Base-line geomorphic data have already been collected for the disturbed stream reach. Resource management staff and the seasonal employee will use photo-point monitoring techniques to assess stream corridor recovery, and conduct a follow-up geomorphic assessment three years after the fence is constructed.

See Appendix D for Visitor Access associated project statement

Sewage and Hazardous Waste

Sewage infrastructure serving the headquarters complex dates to the Civilian Conservation Corps era (1930s) and at one time utilized spray fields in lower Frijoles Canyon (National Park Service and U.S. Department of Energy, 1993). In 1973, a lift station was installed and sewage was then pumped over 500 feet in elevation to the mesa north of the headquarters into a series of lined lagoons. Greater visitation necessitated a 1993 project that enlarged the lagoon capacity. Problems and potential problems associated with this system include leakage from the collection network, and overflows near the lift station.

Jacobs (1996) reported blockage of the Bandelier sewer system in the main parking area at the gravity collection junction and manhole cover near the footbridge that resulted in the spillage of raw sewage into Frijoles Creek. He also stated that this was the second spillage he was aware of in 3 years. Maintenance staff believe conversion to low-flow toilets increased the solids to water ratio overwhelming the design capacity of the gravity collection network (i.e. gradient too low) under certain conditions. The series of lined lagoons appear to be working well and are large enough to handle significant visitor use increases.

High fecal coliform counts are often observed in Frijoles Creek at and below the Monument headquarters relative to upstream sites and periods of lower visitation (Bracker, 1995). Monument staff is concerned that subsurface leakage from the sewage collection and/or pumping system is migrating to Frijoles Creek. This is based mainly on fecal coliform monitoring results; however, there is no clear link between the sewage infrastructure and high fecal coliform counts. The discovery of *bis* (2-ethylhexyl) phthalate by Purtymun et al. (1988) in Frijoles Creek at levels similar to those observed below a sewage treatment plant in Los Alamos County lends additional credence to this concern. Other potential explanations/sources include:

1. High phthalate concentrations could have resulted from a direct spill from the lift station.
2. Leachate from unlined pit toilets at Ceremonial Cave could produce elevated fecal coliform during the busy season (these pit toilets have been replaced with vault toilets).
3. Natural sources, such as the turkey vulture roost in the Frijoles riparian area, could add fecal coliforms to the stream on a seasonal basis.
4. Storm flows could wash naturally occurring bacteria, and backcountry human and horse waste, into the stream. Recent work by Steele (pers. comm., Fayetteville, AR, 1998) shows bacteria can remain viable in stream sediments for a time far in excess of reported half-lives. Visitors wading in Frijoles Creek near the picnic area can stir up these sediments, re-suspending bacteria in the water column.

Because the headquarters infrastructure is located within Frijoles Canyon, proper management and disposal of hazardous materials is critical to protecting ground and surface water resources. Bandelier recognizes the need to control hazardous materials incidents and to minimize their impacts should they occur, and has prepared a *Hazardous Materials Management Standard Operating Procedures* manual in compliance with NPS management Policies (Bandelier National Monument, 1996). The visitor parking and maintenance area are potential sources of spills, and an emergency response section is also included in the *Hazardous Materials Management Standard Operating Procedures* manual.

<u>*Recommendation*</u>: Past water quality data and the general condition of the headquarters sewage infrastructure points to the need for further addressing possible sewage contamination. The most obvious need is the replacement or retrofitting of the gravity feed network to alleviate problems that result in sewage overflow to Frijoles Creek. Repair/rehab maintenance funding appears to provide the best avenue for securing needed resources to deal with this obvious health and safety concern.

Less obvious is the potential for chronic leakage to ground water or Frijoles Creek from cracks in subsurface sewage lines. Investigations should include installation of shallow ground water monitoring wells, use of tracer dyes, screening both surface and ground water for optical brighteners and caffeine, and DNA analysis of fecal coliform colonies to determine the source of these indicator organisms. The ground water work would also yield contaminant information relative to Los Alamos National Laboratory, and should be coordinated with LANL and the New Mexico Department of Environmental Quality LANL Oversight Bureau.

See Appendix D for Sewage associated project statement

Flood Plain Management

Flood plain Management Guidelines issued by the National Park Service (1993) require NPS units to avoid direct and indirect flood plain development wherever there is a practical alternative. At Bandelier, development of the Frijoles Creek flood plain includes pre-historic, historic, and modern structures. This infrastructure predates the 1977 Executive Order (11988) that originally required federal agencies to avoid occupancy and modification of flood plains. The Executive Order and NPS management guidelines also require reducing the risk of flood loss through the implementation of flood plain planning and restoration of natural and beneficial values of flood plains. When the regulatory floodplain must be used, mitigation needs to be employed to protect up to the regulatory flood plain level.

In compliance with Executive Order 11988, a flood hazard survey was completed for Frijoles Canyon in 1987 (National Park Service, 1995a). Flood frequency data derived from U.S. Army Corps of Engineers (COE) regionalized graphs, along with cross-sections developed by NPS staff, were used to estimate 10-year, 50-year, 100-year, and 500-year flood plain elevations for Frijoles Creek near Monument headquarters. Water surface elevations were predicted using the COE's HEC-2 computer program. Maps and tables were produced showing the area inundated and maximum depth of flow for each event (U.S. Army Corps of Engineers, 1987).

The 100-year and 500-year flood plains were delineated on a 1935 topographic map constructed by the National Park Service with a contour interval of 10 feet. Past review of this map by park staff indicated that a 100-year flood would inundate the picnic area and its restrooms, along with the backcountry parking lot, and the lower parking lot at the visitor center. A 500-year flood would reach the visitor center (restroom wing), museum, maintenance facility (wood/welding shop, oil house, and lumber storage), and the search and rescue and fire cache. Maximum flood depths in the vicinity of the headquarters infrastructure area would be 12.2 feet with a maximum width of 320 feet for the 100-year flood, and 13.6 feet and a maximum width of 364 feet for the 500-year flood.

The farthest downstream cross-section that was modeled was completed near the same location as the USGS gauging station. The largest flood of record at this gauge (3,030 cfs) attained a maximum stage height of 6.34 feet (between 5.0 and 5.5 feet above channel thalweg). The 100-year and 500-year flows from the COE study were 2,750 cfs and 6,500 cfs, respectively. It is apparent that the routing equations used by the COE were in error, and that it failed to crosscheck the predicted stage/discharge relationships with actual USGS measurements. Predicted stage height (12.2 feet) for the modeled 100-year flood (2,750 cfs) is over twice the actual stage height observed during a 3,030 cfs event.

McLin (1992) used HEC-1 and the predicted 100-year, 6-hour design storm for the Los Alamos area to generate hydrographs for Frijoles and other watersheds in and near LANL. Predicted HEC-1 peaks along with stream channel geometry and basin characteristics were used to compute the 100-year flood plain elevations. Similar techniques were used to model other recurrence interval storms and flows, and comparisons were made to USGS flood-flow

frequency equations but not actual discharge records. McLin appears to justify the accuracy of his results based on his and other's personal observation of stream response to actual storms. It is interesting to note that peak discharge for a two-year recurrence event in a 20 mi^2 watershed is about 15 cfs, which is very similar to pre- and post-fire maximum observed flows from Frijoles and Capulin Canyons. McLin made no effort to include the relationship between fire and runoff as a potential complicating factor in the model.

Taken from McLin's work is a graph of various return interval flows for Frijoles Creek at the USGS gauging station (Figure 27). Note that the 100-year flood has a peak calculated discharge of 853 cfs, significantly less than both the COE predicted 100-year flow of 2,750 cfs and the maximum post-fire observed flow of 3,030 cfs. Using McLin's graph and employing the equation for the best-fit line, a flood of 3,030 cfs would have a predicted recurrence interval in excess of 4 million-years. This is of note because McLin states "an observed 100-yr 6-h storm has never been recorded at Los Alamos," yet according to his calculations, a 4-million year flow event has been observed.

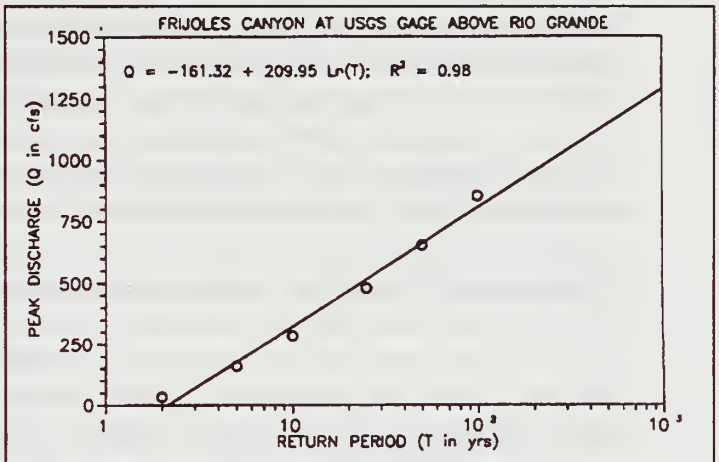

Figure 27. Peak Discharge as a Function of Return Period for Frijoles Creek (McLin, 1992).

It is hoped that the above and previous discussions lead the reader to agree that reliance on hydrologic modeling that employs regional curves or generalized parameters can be misleading. The watershed responses to precipitation on the Pajarito Plateau are unusual if not unique. General field observations are probably more important than detailed mathematical modeling and include:

1. The magnitude of historic flooding has less to do with the size of precipitation events than the condition of the watershed;
2. Geomorphic and tree scar evidence indicates floods even larger than observed post-fire floods have occurred in Monument streams. The cause of these floods is unknown, but a 9,000 to 10,500 cfs flood as determined for past floods on Capulin Creek would cause major damage to the headquarters infrastructure if it occurred in Frijoles Canyon;
3. Outbreak flooding from washout of localized landslides appears to be a possible mechanism for explaining large floods;
4. Overbank flows resulting from debris jams (especially where the channel is restricted by bridges) has the potential to flood headquarters facilities even during relatively minor flows, making concern over specific return interval floods inconsequential;
5. Even the large post-fire floods did relatively little infrastructure damage, only causing minor flooding of the visitor center; and,

6. The possibility of flooding the headquarters complex appears to be greatly reduced by management of the watershed in keeping with historic fire regimes and vegetative assemblages.

Recommendation: The first recommendation dealing with infrastructure on the flood plain is to have a qualified geomorphologist assess the potential for outbreak and overflow flooding in both Frijoles and Capulin Canyons. The study reach on Frijoles would include the section above the headquarters, while on Capulin it should focus on the reach above the Base Camp, which is required occupancy for NPS personnel during back-country patrols. Landslides and slumps in these canyon systems have been documented in the past. Recent destabilization of Capulin Canyon increases the likelihood of localized mass-movement. The principal question is whether the size of the slump or slide material is large enough relative to the streams transport power as to preclude a near instantaneous breach of the slide dam.

See Appendix D for Flood Plain associated project statement.

The second recommendation has been previously stated under the watershed management section. It involves restoration of natural fire regimes and vegetative communities, which in turn should reduce the magnitude and frequency of large floods.

The third recommendation is related to debris jams which might cause overbank flows. Bandelier should remove debris jams from the headquarters reach of Frijoles Creek only when they might cause flooding which could be a threat to life or property. Removal should be done with the least stream damage possible. Some woody debris should remain as it provides the best habitat in this otherwise degraded reach of stream. Flood hazard delineation procedures could also be used to assess the potential for overbank flows to impact park structures.

In the previous discussion, the limitations of past flood plain delineations were reviewed. However, regulatory flood plains must be delineated in NPS settings such as the Frijoles headquarters operation. It is recommended that the Corps of Engineers 100-year and 500-year flood elevation data continue to be used for this purpose because they provide conservative over-estimates of the regulatory flood plains. These elevation data should be used to generate regulatory flood plains on 7.5-minute topographic maps.

An obvious consideration applicable to the infrastructure issue is the relocation of the headquarters out of Frijoles Canyon. This would be the ultimate recommendation regarding visitor access, sewage, and flood plain issues, and best address water resource protection.

Fish Management

Bandelier's complement of fish species appears to consist of three non-native, yet naturalized trout species. Historical accounts, the physical setting, and regional fish distribution patterns have led area fisheries biologists to conclude that Rio Grande cutthroat trout were once native to the Monument's perennial streams, specifically Frijoles Creek. However, definitive proof of Rio Grande cutthroat trout in the Monument is not available and probably never will be, mainly

because cutthroat trout would have been extirpated by stocking of exotic trout early in the 20th century.

Primack (1993) pointed out that whereas patterns of evolution have proceeded as a result of geographic isolation, humans have radically altered this pattern by transporting species throughout the world. Any introduced species that survives the transfer necessarily affects the receiving ecosystem. Courtenay (1993) summarized that every introduction will result in impacts to the native biota, which range from almost nil to major, including extinction, with time. Nonnative species can affect native species through a number of mechanisms including hybridization, competition, predation, pathogen transfer, and habitat alteration.

Proposals dating back at least to 1961 called for the (re) introduction of Rio Grande cutthroat in Frijoles Creek, the earliest of these originated from National Park Service fisheries personnel (NPS, 1978). Frijoles Creek is attractive for the (re) introduction program because of the natural barriers, wilderness designation, relatively low fishing pressure, and absence of cattle grazing, among others. New Mexico Department of Game and Fish has successfully re-introduced this species in at least 45 other locations (Rinne, 1995).

Bandelier's management appeared willing to pursue the cutthroat stocking program in the late 1970s (NPS, 1978). However, current managers note that there are two separate issues: 1) eradicate non-native trout species without further damaging the ecosystem. They are specifically concerned with chemical extermination (such as rotenone and antimycin, common fish toxicants) and its affect on other aquatic organisms, such as benthic macroinvertebrates. However, it is important to realize that exotic trout are tampering with the natural ecosystem (aquatic macroinvertebrates) as well; and 2) should Rio Grande cutthroat trout be stocked in Frijoles Creek? – substantial uncertainty exists about whether this trout species is native to the creek. They also fear that with the easy access to this stream, unauthorized private restocking of exotic trout would again eliminate the native cutthroats.

Recommendation: Management Policies of the National Park Service (1988) state "In natural, cultural, and park development zones, fisheries management will seek to preserve or restore natural aquatic habitats and the natural abundance and distribution of native species, including fish, together with the associated terrestrial habitats and species...Artificial stocking of native fish will be employed in natural areas only to reestablish native species in their historic ranges". Relative to exotic species NPS policy states "Management of populations of exotic plant and animal species, up to and including eradication, will be undertaken wherever such species threaten park resources." It further states "Examples of threatening situations include: interfering with natural processes and the perpetuation of natural features or native species, especially those that are endangered, threatened, or otherwise unique." Bandelier management used the above and related policy guidelines to remove feral cattle and burros from the Monument. It is the opinion of the author that exotic trout are having greater impacts on aquatic communities, mainly because they negate any possibility of native fish reintroduction.

Bandelier should evaluate the potential of using electroshocking and other alternative eradication techniques to remove exotic trout from its streams. As an example, personnel at Great Smoky Mountains National Park have had documented success eradicating exotic trout species from

selected stream reaches using multi-pass electroshocking (Kulp, pers.comm., Great Smoky Mountains National Park, 1998; Larson et. al., 1986). Park staff should also contact the New Mexico Game and Fish Department and see if they are still interested in (re) introducing native cutthroat to Frijoles Creek.

A recent agreement between the Jicarilla Apache tribe, New Mexico Department of Game and Fish, and the U.S. Fish and Wildlife Service to reestablish this subspecies on tribal lands in the nearby Rio Chama basin indicates partnerships are still being implemented to pursue this goal (U.S. Department of Interior, 1998). Additionally, further investigations (e.g. examination of fish bones from archeological digs) could be conducted to determine the probability that Rio Grande cutthroat once swam Bandelier's waters. Replacement of exotic species with regional natives appears to be a preferred course of action based on NPS management policies. However, the suitability of Frijoles Creek for species restoration must be determined, given Allen's (pers. comm., Bandelier National Monument, 1999) finding that Frijoles Creek went dry several times this past century. In other words, the flow variability of this creek (or that of any other of Bandelier's creeks) might not allow the successful establishment of the Rio Grande cutthroat trout, although nonnative trout have persisted in Frijoles Creek sans stocking for 45 years.

Environmental assessments provide a mechanism to plan a project and to select the best alternative that will accomplish the goals and objectives. A comparison of alternative actions and the potential impacts are vital to the success of the project and such planning should be axiomatic in any restoration program (Wiley and Wydoski, 1993). An environmental assessment for the restoration of Rio Grande cutthroat trout to Frijoles will not only evaluate the relative impacts of the program (i.e. action vs. no action), but also evaluate various techniques to accomplish the restoration (i.e. chemical vs. mechanical vs. integrated). The environmental assessment should be a cooperative effort between the National Park Service, New Mexico Department of Game and Fish, and U.S. Fish and Wildlife Service. A technical assistance request has been developed to request agency fisheries experts to perform preliminary assessments and develop a mutually acceptable course of action.

See Appendix D for Fish Management associated project statement.

Los Alamos National Laboratory

Radioactive and hazardous waste has been generated and disposed at Los Alamos National Laboratory since its inception in 1943. More than 2,000 potentially contaminated sites or solid waste management units were recognized by LANL in 1995 (Stone, 1996). In 1979, it was estimated that about three million pounds of solid radioactive waste were buried in trenches and shafts dotting LANL's mesas (Stevens, 1982). Abrahams (1963) stated that radioactive wastes from Los Alamos have been released into the air, onto the surface, and into the subsurface in unknown quantities.

Abrahams' early work recognized that while most buried plutonium was retained in the tuff, isolated areas existed where water carried the "activity" through joints to greater depths (Abrahams, 1963). Dale (1996) reports that historically, LANL disposed of a portion of its

liquid radioactive waste by discharging to canyons, underground storage tanks, and absorption beds. Previous studies and ongoing work reported by Dale showed radionuclides, in both the suspended and dissolved phase, were detected in storm runoff and moved off-site, although total quantities are unknown. Periodic releases of hazardous and radioactive wastes to the atmosphere have also been documented.

A review of the literature generated from water resource and contaminants investigations at LANL clearly indicate widespread and significant volumes of hazardous and radionuclide materials present in the environment. There are three potential pathways for this material to move into Bandelier:

1. Groundwater movement, specifically from perched zones;
2. Sediment and storm-water transport off-site with subsequent deposition in the backwaters of Cochiti Reservoir within the flooded portions of Bandelier; and
3. Atmospheric and eolian transport and deposition.

Ground Water

There are no streams or drainages that flow directly from LANL onto Bandelier. There are also no streams which flow from LANL to the Rio Grande under base flow conditions (Purtymun and others, 1980). Ultimately, all streams within LANL are losing streams. This is significant given that total effluent releases from sewage and other treatment plants in and near the Laboratory are over three times greater than incoming stream-flow onto the Laboratory (LANL, 1998b). Over the past five decades, this surface infiltration has recharged subsurface waters that have thereby accumulated contaminants.

Examples of ground water contamination include tritium contamination in four, intermediate-depth, perched ground water locations in lower Los Alamos Canyon. Well LADP-3 is down gradient from the Omega Reactor, which was discovered in 1993 to have been leaking tritiated cooling water for some time (Rogers et al., 1996b). Analysis of water from Ancho Spring indicates the presence of numerous constituents that are found in high explosives and trace levels of depleted uranium. Boreholes drilled through or next to absorption beds or angled beneath waste disposal shafts encountered primarily Pu, AM, 137-Cs, 90-Sr (Los Alamos National Laboratory, 1998b).

Stone (1996) focused on ground water issues and presented ten unanswered questions related to the complex nature of the many zones of water beneath the Pajarito Plateau and its canyons:

1. How many perched water zones are there?
2. How deep is the ground water?
3. What is the lateral extent of the perched water zones?
4. Is there recharge through the tuff?
5. What is the ground water flow direction around the well fields?
6. Why are all the springs in the White Rock Canyon attributed to the main aquifer?
7. Where does perched ground water below the Pajarito Plateau go?
8. What is the water budget of the Pajarito Plateau?

9. What is the background hydrochemistry for each of the saturated zones?
10. What is the inventory of radionuclides in the canyons?

In response to documented ground water contamination and the need to answer basic ground water questions, LANL has developed a comprehensive *Hydrogeologic Workplan* (LANL, 1998b). This document describes activities to be performed by Los Alamos National Laboratory to characterize the hydrogeologic setting beneath the laboratory, and enhance the laboratory's groundwater monitoring program. The planning was completed with close oversight from the New Mexico Environmental Department that stated four issues and questions that the Department considered unresolved:

1. Individual zones of saturation beneath the Laboratory have not been adequately delineated, and the "hydraulic interconnection" between these is not understood;
2. The recharge area(s) for the regional aquifer and intermediate perched zones have not been identified, and the effect of fracture-fault zones on recharge is unknown;
3. The ground-water flow direction(s) of the regional aquifer and intermediate perched zones, as influenced by pumping of production wells are unknown; and,
4. Aquifer characteristics cannot be determined without additional monitoring wells installed within the specific intervals of the various aquifers beneath the facility.

These questions are also pertinent to Bandelier because of the potential for perched water zones recharged below LANL, to contribute flow to Frijoles Creek or possibly Alamo Canyon (Reneau, 1998). Reneau also reports that geologic and geohydrologic knowledge of Bandelier's subsurface is changing rapidly as a result of the implementation of the *Hydrogeologic Workplan* and that "New wells have demonstrated contamination deeper and in different places than previously recognized."

One potential transport path for these contaminants is shown in Figure 28. This structural contour map shows the elevation of the base of the Bandelier Tuff, which is recognized as a perching boundary due to the relatively impermeable nature of the underlying basalt. The map also shows the inferred flow direction of perched water within the basal Guaje Pumice Bed --- south toward Bandelier National Monument. Because the lowest structural contour line is 6,100 feet and an outcrop of basalt in the Frijoles channel was observed near the Frijoles gauge at an elevation of approximately 6,040 feet, water perched on the basalt could add recharge to Frijoles Creek. Even without the existence of the trough, alluvial recharge of perched water zones below Ancho or other LANL canyons to the North, could provide positive flow and contaminants to Frijoles Creek.

Another potential ground water transport path from LANL to Bandelier is through the Pajarito Fault zone. Purtymun and Adams (1980) measured increased flow in Frijoles Creek as it passed through this fault zone. The source of this water input is unknown but could include recharge from western areas of LANL. Fractures within basalt can also lead to the development of secondary porosity, increasing hydrologic conductivity and contaminant transport. In 1996, low levels of constituents found in high explosives were detected in Frijoles Creek at Monument Headquarters (Los Alamos National Laboratory, 1998a).

Recommendation: LANL should install ground water monitoring wells near the axis of the structural trough to determine potential occurrence of ground water and contaminants. Examination of proposed well locations also shown in Figure 28 indicates well R-27, 28 and 30 come closest to fulfilling this recommendation. According to Reneau (1998), while these wells are intended to be completed within the deeper regional aquifer, any encountered perched ground water zones will also be sampled and characterized. Other wells in this area will help confirm flow paths and aquifer tests should reveal important information concerning ground water flow rates. Bandelier staff should continue their dialogue with LANL as the *Hydrogeologic Workplan* is implemented and contact NPS Water Resource Division hydrogeologists for assistance in interpreting results and formulating new recommendations based on the wealth of new information resulting from these investigations. Bandelier is currently negotiating through the Natural Resources Trustee Council to have the Department of Energy staff a professional at the Monument for the next ten years to interpret water resource investigations and contaminant results from LANL investigations. This action is highly recommended.

A series of detailed seepage runs should be performed on the entire length of Frijoles and Alamo creeks. A seepage run is a series of meticulously accurate discharge measurements taken at close intervals along a stream. The purpose is to locate gaining and losing reaches and quantify ground water inputs or surface infiltration. These are relatively rapid and inexpensive measurements and should be conducted during various times of the year and differing levels of base flow. For example, measurements taken near the end of the spring snowmelt could reveal areas receiving a high degree of recharge from higher elevations, such as in the vicinity of the Pajarito Fault zone. Measurements taken in times of lowest base-flow when ground water losses, and in some cases inputs, are at their relative highest, will reveal areas influenced by perched ground water. Finally, a seepage run conducted when the plant community is dormant and evaporation is relatively low (late fall) would show the relative influence of evapotranspiration on canyon water budgets.

See Appendix D for associated Ground Water project statement

Bandelier staff should also discuss the idea of locating shallow ground water monitoring wells within the alluvial sediments of Frijoles Canyon. These wells would be small and relatively minor intrusions on the already developed headquarters landscape. They would provide information for the use of LANL, NMED, and Bandelier as discussed under the Sewage and Hazardous Waste section. The dominant purpose under the context of LANL would be to determine fluctuations in alluvial ground water levels within the canyon and flow directions relative to the stream. These wells could also provide additional perimeter ground water contaminant information. The New Mexico Environmental Department, U.S. Department of Energy Oversight Bureau should be contacted to help with coordinating the project and providing technical guidance.

Finally, it is recommended that Monument staff develop closer working relations with the NMED oversight personnel. NMED should be made aware of the NPS's desire to maintain an environment free of hazardous and radioactive waste. Park staff could also request local experts with this office to review LANL's off-site monitoring and characterization programs to determine if they are adequately addressing the needs of this important public recreation area.

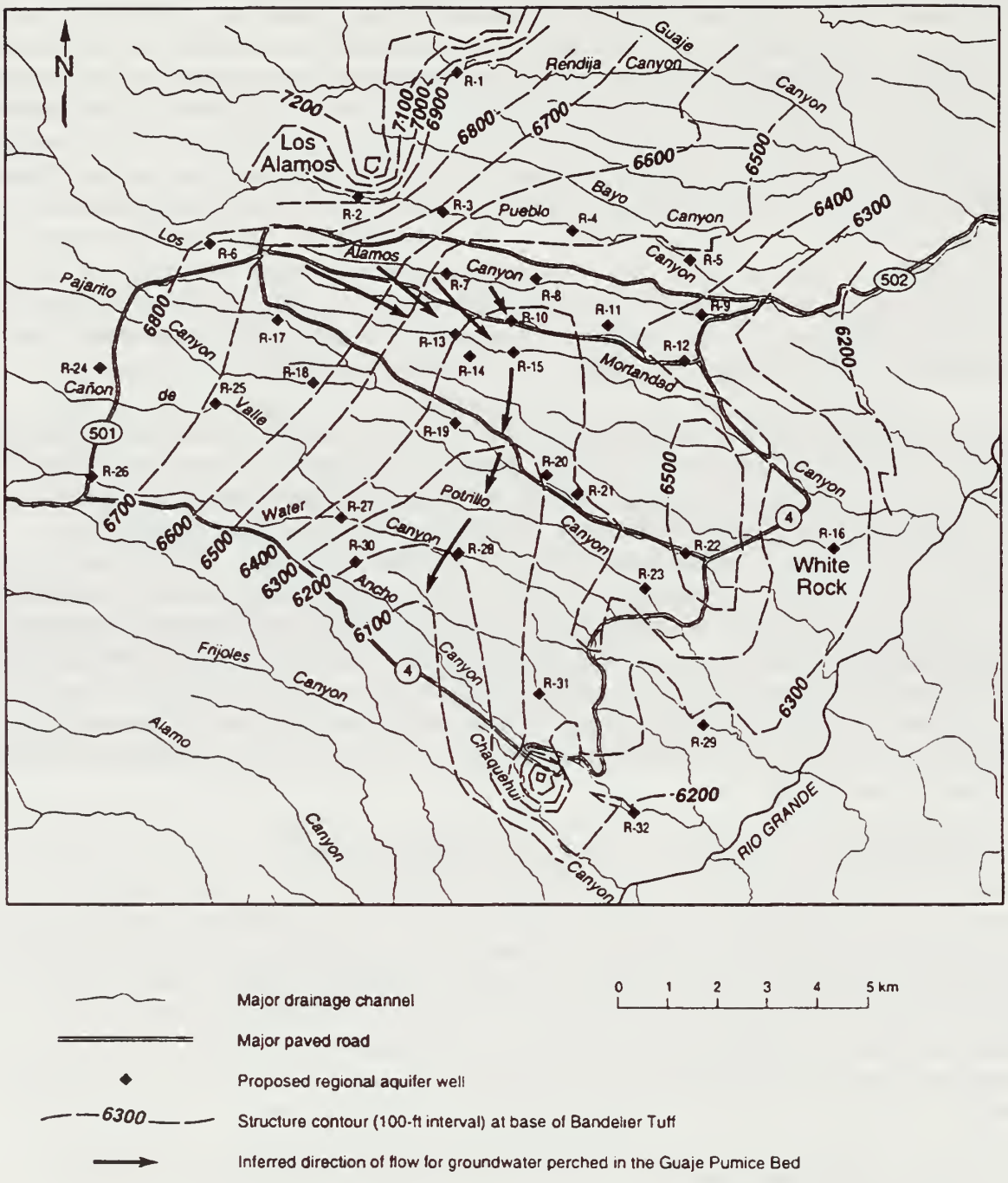

Figure 28. Inferred Direction of Perched Ground Water Flow Below Los Alamos National Laboratory and Locations of Proposed Regional Aquifer Monitoring Wells (LANL, 1998b).

Sediments

Sediment samples are collected in the LANL region, including Frijoles Creek and upper Cochiti Reservoir, for USDOE and NMED to monitor the environmental effects of LANL operations. Sediment samples are analyzed for the presence of radionuclides, metals, and organics as part of LANL environmental surveillance and compliance program. These studies show natural stream processes have moved contaminated materials out of canyons, especially from Acid Canyon, and into the Rio Grande (U.S. Department of Energy, 1998; Graf, 1993).

The Department of Energy continues to monitor the movement of sediments across LANL and into the Rio Grande (U.S. Department of Energy, 1998). These studies have found that off-site transport of sediments with elevated plutonium-239 and -240 levels has taken place. Sediments collected at Cochiti Lake over a six-year period had mean plutonium concentrations 23 times higher than sediments from a background monitoring station at Abuquiu Reservoir.

Recommendation: Relatively little can be done about the deposition of sediments with elevated plutonium levels and other potential contaminants within flooded portions of Bandelier. It is hoped that LANL management practices have effectively eliminated significant outputs of radioactive contamination and that the USDOE is in the process of cleaning up existing sources. This should eventually result in decreased loading of radioactive sediments within Cochiti's backwaters. Continued monitoring of sediments by LANL should be conducted at levels specified by the NMED. Bandelier staff should consult with representatives from the NMED to determine appropriate levels of action to insure visitor safety within this area, and whether or not they should be informing visitors about this situation.

Atmospheric Transport

Atmospheric releases of hazardous and radioactive contaminants from LANL operations have occurred and are ongoing. Atmospheric discharges are considered a more diffuse source with little chance for significant contamination of Bandelier's water. Current releases were reported to be below State of New Mexico standards (U.S. Department of Energy, 1998). Because of the relatively low level of these releases and the dispersed nature of atmospheric transport, it is not anticipated, nor has it been reported that atmospheric deposition of radionuclides or hazardous materials from LANL operations is significantly above natural background levels.

Recommendation: Air quality and related atmospheric monitoring at LANL is sufficient to evaluate atmospheric transport of radionuclides or other hazardous materials that might harm Bandelier's water resources. Action levels related to nearby communities and Laboratory personnel would trigger a shutdown or remedial action plan before any impacts are detected at the Monument.

Cochiti Reservoir

Cochiti Reservoir seasonally inundates the lower elevations of White Rock Canyon, including about 350 acres of Bandelier and the mouth of every canyon in the Monument. Impacts from the management of Cochiti Reservoir include the loss of native vegetation and introduction of the exotics (including tamarisk); burial and extirpation from the Monument of six plant species

previously found associated with springs; submergence of cultural sites; slumping of saturated canyon wall colluvium; and, the general degradation of the area through deposition of debris along contour lines (Allen 1989a; Allen et al., 1993; National Park Service, 1995a).

Resource losses are apparently superseded by a 1977 Memorandum of Understanding between the National Park Service and the U.S. Army Corps of Engineers which states, in part, that NPS lands "shall be subject to such flooding and inundation as is required for the operation of said project" (National Park Service and U.S. Army Corps of Engineers, 1977). Said project was authorized as multi-purpose, including flood/sediment control for the Rio Grande Valley through the 1960 Flood Control Act (PL86-645) and to provide a permanent pool at the Cochiti Dam site (PL88-293) for the development of "fish and wildlife resources, conservation and recreation purposes." The challenge for area managers is to provide flood and sediment control while maximizing natural resource, conservation, and recreational benefits.

Bandelier's Superintendent (Weaver, 1991) stated that discussions between the National Park Service and the U.S. Army Corps of Engineers leading to the signing of the Memorandum of Understanding indicated that only temporary flooding (interception of spring runoff to attenuate downstream flood peaks) of the Monument would occur. Since that time, flooding has exceeded "temporary" time frames and has created problems not anticipated by the signatories. This is evident in Figure 20 which shows storage of flood waters on a "temporary", year-round basis, during the late 1980s. Weaver recommended that present managers should not be burdened by the inability of earlier managers to anticipate changes in operation or practice. He requested that the two agencies develop amendments to the 1977 Memorandum of Understanding addressing problems created by longer periods of flooding. Until a new memorandum was signed recently, operation of the reservoir since the late 1980s was closer to the temporary time frames originally articulated.

While the Memorandum of Understanding clearly permits temporary flooding within the Monument, it does not address permanent flooding or the burial of the Monument under backwater sediments. As discussed previously and displayed in Figures 18, continually rising lake levels are required to maintain a 1200-acre recreation pool to offset surface reduction caused by sedimentation in the upstream delta (Johnson, 1995). The rate of burial is estimated to be consistent with the rate at which the recreation pool is adjusted, 0.89 feet per year.

This pool adjustment and sediment burial could theoretically continue to the elevation of Cochiti Dam's spillway at 5,450 feet. At current rates of upward adjustment, the spillway notch elevation would be reached in about 110 years. Kreiner (pers. comm., U.S. Army Corps of Engineers, 1998) stated that the rate of adjustment should slow in the coming years because the delta is building into wider reaches of the reservoir, requiring more sediment volume per unit of elevation. However, it should be noted that continual upward adjustment of the pool forces maximum sedimentation to occur in more or less the same reach (between mile 4 and 7 as shown in Figure 18).

In 1991, the Middle Rio Grande Conservancy District (MRGCD) asked the U.S. Army Corps of Engineers to consider re-authorization of Cochiti Reservoir to provide up to 5,000 acre-feet of irrigation storage. This would require the creation of a conservation pool that would flood

greater portions of Bandelier for even longer periods of time (U.S. Army Corps of Engineers, 1989) and create additional resource damage within the park (National Park Service, 1995a). In response to the MRGCD request, an Interagency Biological Working Group (IBWG) was formed to determine the impacts of a conservation pool on the natural resources of the affected area.

After nearly 2 years of study, the IBWG produced a report and recommendations stating that re-regulation of the reservoir was environmentally unsound, and recommended rejection of the re-regulation proposal (Allen et al., 1993). Among other concerns, they pointed out that 66 acres of delta wetland would be flooded and degraded by the proposed re-regulation storage. The Corps of Engineers stated that unless concerns of the IBWG were successfully resolved, they would not consider going further to amend the Cochiti Reservoir authorization legislation to permit water storage (Weaver, 1995).

The IBWG further stated that significant, unrealized opportunities exist within the current authorization to greatly enhance management for fish, wildlife, and recreation at Cochiti Reservoir, and still meet the primary flood and sediment control purposes for the dam. The IBWG envisions a "desired future condition" for Cochiti Reservoir as a diverse, productive ecosystem occupying a strategic location on the Rio Grande flyway (Allen et al., 1993). Thus the interagency working group recommends implementation of the following management measures for Cochiti Reservoir, all of which can be implemented within the current authorization:

1. Avoid carryover storage;
2. Maintain adequate flow capacity on the Rio Grande below Cochiti Dam to avoid carryover storage in Cochiti Reservoir;
3. Restore vegetation that has been impacted by prolonged water storage,
4. Use the improved annual operation scenario outlined in Figure 29 as a guide for operating Cochiti Reservoir;
5. Review all petitions for extraordinary water holding operations to insure consistency with the reservoir's operation, including fish and wildlife; and,
6. Develop and maintain a single interagency biological team to enhance the ecological condition of Cochiti Lake and its delta.

The Interagency Biological Working Group also created a Memorandum of Understanding between U.S. Army Corps of Engineers, National Park Service, Department of Energy, U.S. Geological Survey, New Mexico Department of Game and Fish, New Mexico Ecological Services Office, U.S. Fish and Wildlife

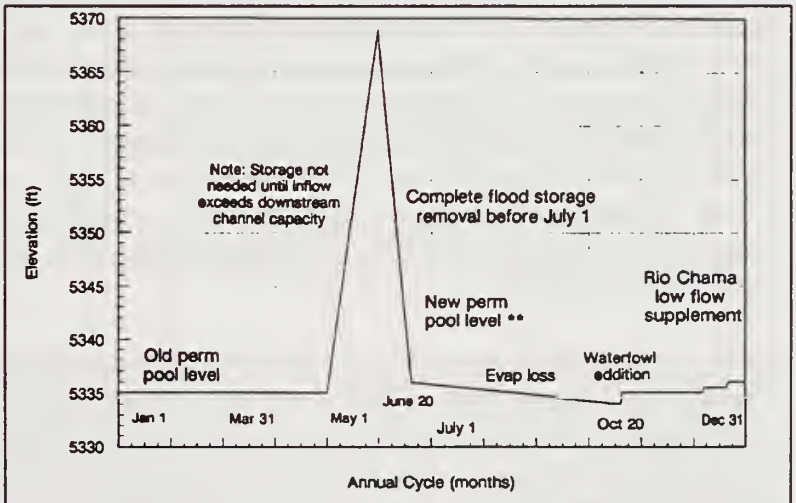

Figure 29. Proposed Annual Operation of Cochiti Reservoir (Allen et. al., 1993).

Service, Pueblo De Cochiti, U.S. Forest Service, and University of California. The purpose of the new Memorandum of Understanding is to set up a framework by which the above named parties mutually agree to work together to enhance the communication, discussion, and resolution of issues pertaining to physical, biological and recreational resources and their management in the vicinity of Cochiti Lake and White Rock Canyon, New Mexico. It would also establish a Cochiti Lake Ecological Advisory Team, composed of representatives from each entity, as a forum for information exchange, discussion, and coordination (Allen et al., 1993). The new Memorandum has been signed recently by the involved parties.

Recommendation: Bandelier's staff and management have effectively dealt with a fundamentally irreversible situation and subsequent attempts to make it even worse. In the West, water management for consumptive uses takes precedence over almost any other consideration. Bandelier's approach, consisting of stressing Cochiti's wildlife management mandate, justifying issues through application of resource information, and formulating and articulating feasible alternatives which meet Cochiti's other legislated mandates while enhancing the natural resource attributes of the emerging delta, is highly commendable. Meeting new threats on a unified front through the efforts of the Interagency Biological Working Group is also laudable. Bandelier's success is due in large part to a highly competent resource staff.

Also important, the U.S. Army Corps of Engineers has not been alienated by Bandelier's approach. Kreiner (1998, pers. comm.) recommended having a doctoral thesis developed with the purpose of scoping out the best way to meet all of Cochiti's mandates, now and in the future. Bandelier should discuss the possibility of helping initiate such a project if they do not feel the IBWG has already accomplished this goal. National Park Service moneys might be well spent matching COE dollars to initiate such a project. Water Resource Division personnel could attend meetings or otherwise help devise specific resource questions.

DDT

From the early 1950s to 1966, Bandelier used DDT and other chlorinated hydrocarbons for pest control near the developed headquarters area (Allen, 1989a; Fletcher, 1990; National Park Service, 1996b). At first a hydraulic sprayer was used, but aerial spraying was started in 1952. For example, in 1953 300 acres were sprayed by air with 85 gallons of formulated DDT (Allen, 1989a). Bandelier's maintenance yard was used as a storage and operating area for pesticide spraying activities. Unknown quantities of DDT solution entered the maintenance yard drainage system that was designed to collect and transport liquids to one or two lower sumps near Frijoles Creek. All materials washing into these sumps, including DDT contaminants, subsequently percolated into surrounding soils and entered the aquatic and terrestrial ecosystems (National Park Service, 1995a).

In 1975, the State of New Mexico discovered high levels of DDT contamination in Frijoles Creek. Fletcher and Allen (1990) sampled the entire canyon, finding DDT contamination of up to 164 ppm adjacent to Frijoles Creek near the headquarters parking lot. Dr. Fletcher also found one DDT contaminated bat during his investigations. Fish samples collected in 1993 by the U.S. Geological Survey below the headquarters parking lot were found to contain high levels of DDT

and its isomers, generally 5 to 10 ppm (National Park Service, 1995a; National Park Service, 1996b).

U.S. Geological Survey-NAWQA whole-body fish sampling on Frijoles Creek showed the highest concentrations of DDT related species of any of the 17 Rio Grande study area sites (Carter, 1994). The persistent environmental effect of DDT at the Frijoles Creek site is demonstrated by a greater number of DDT compounds exceeding the minimum reporting level in bed-sediment and whole-body rainbow trout samples as compared to samples from the other sites. While the Frijoles Creek bed-sediment and whole-fish concentrations were much higher than in the other sites sampled, the concentration is not exceedingly high when compared with concentrations in other parts of the Rio Grande basin (Carter, 1997a). The presence of o,p'-DDT in both bed-sediment and whole-body fish samples from Frijoles Creek suggests a point source of DDT (Carter, 1997b).

In 1992, the park received approval to implement a *Remediation and Cleanup Plan for Three DDT Contaminated Sites*. RHOMBUS, Inc. (1995) was contracted to determine where DDT and its isomers equal or exceed 1 ppm, locate contaminated sump(s) and associated drainage line(s), and develop Scopes of Work to complete remedial actions. The main source, a drainage sump near the maintenance compound, was believed to be discovered and removed during these investigations in December 1993 (National Park Service, 1995a).

Bandelier National Monument subsequently contracted with Ecology and Environment, Inc., to prepare a risk assessment, consistent with EPA protocols for a DDT-contaminated site. The assessment was completed in March, 1996, with the following conclusions and recommendations (National Park Service, 1996b):

- Remediation of the DDT-T contaminated soils or sediments is not warranted on the basis of ecological risk, potential human health impacts, or the direct risk to significant cultural resources;
- Remediation of DDT-T contaminated soils in the historic gutter along the entrance road is not warranted. Normal maintenance of the gutter should be reinstated to remove the accumulated soils and return the gutter to serviceable condition. This will ensure that no cumulative, significant, indirect impacts will occur to this historic resource;
- Because the DDT-T contaminated soils do not require remediation and no health risks are posed, the existing exclusion of the public from the area near the sumps is no longer necessary; and,
- In addition, Ecology and Environment, Inc., recommended that the current "ban on fishing within the Monument would seem to be proper assuming a preventative public health approach."

Monument managers have followed these recommendations by improving the drainage system in the contaminated area to minimize movement of contaminated soil into Frijoles Creek, and by removing soil and an old wooden bumper in small, highly contaminated areas. They have also maintained the ban on fishing from Ceremonial Cave to the Rio Grande until the edible flesh of fish from the stream is less than the reported EPA threshold level of 5 ppm (NPS, 1996a). Latest sampling conducted by the USGS (Carter, 1997b) found rainbow trout to be significantly less

than the EPA level at only 0.1786 ppm DDT-T. Managers believe a larger and more systematic sampling is needed before the fishery is reopened (National Park Service, 1996b).

Recommendation: Bandelier should develop a plan in conjunction with the State of New Mexico Environmental Department to assess the necessity of the current fishing ban. This State office is a source of specific legal protocols for determining applicability of fisheries bans.

The New Mexico Water Quality Control Commission (1998) continues to list Frijoles Creek as "partially supporting" designated uses as a result of pesticide contamination from past land disposal practices. This story provides an important lesson regarding hazardous material and pesticide management within units of the National Park Service. It is recommended that Bandelier strictly adhere to recommended protocols for storage, use, and disposal of hazardous materials and pesticides, especially in light of the large amount of infrastructure located within the flood plain of Rito de los Frijoles.

External Impacts - Upper Watershed

Most of Bandelier's upper watersheds are under U.S. Forest Service administration (Figure 2). Forest activities that pose a concern to Monument water resources include timber extraction and related silvicultural activities, road construction and maintenance, livestock grazing, off-road vehicle recreation, pesticide and other chemical applications, seeding of non-native grasses, and mineral extraction. While working relations and coordination between the Jemez Ranger District and Bandelier have improved in such areas as fencing, trail maintenance, and fire management, Bandelier's managers believe the potential for additional forest management impacts to the water resources of BAND remains high (National Park Service, 1995a). The New Mexico Water Quality Control Commission (1998) continues to list Capulin Creek as "partially supporting" its designated uses as a result of sediment and turbidity derived from silvicultural activities.

Pippin and Pippin (1980) stated "timber harvesting represents one of the greatest threats to an aquatic community because of the increased potential from flooding and the canopy loss which results in an increase in water temperature." Hydrologic processes that may be affected by logging include interception; infiltration; soil moisture storage; snow accumulation; snowmelt; overland flow; surface erosion; and mass erosion (Stephens, 1982). Since 1983, the U. S. Forest Service-managed headwaters of Alamo and Capulin Canyons west of the park boundary have been logged, along with the headwaters of Sanchez Canyon in 1991 (Allen, 1989a).

Allen (1989b) conducted field inspections and meetings with the USFS concerning their inability to manage timbering operations associated with the Los Utes timber sale in conformance with the project's Environmental Assessment and the Santa Fe National Forest's Forest Plan. Problems he identified included problematic skid trails and landings, and erosion of steep slopes and access roads. Allen (1989b) states "in USFS, portions of Capulin Creek below the [sediment] influx point are heavily choked with sediment...all of this sediment must ultimately flush into Bandelier." Allen recommended that park management participate in the USFS planning process for Bandelier boundary areas and remain involved at a level which allows ensured compliance with the guidelines established during the planning process. Bandelier has a legitimate, established right to participate in these planning efforts based on enabling and other

legislation. Allen further recommended that the USFS take steps to reconstruct access roads to reduce sedimentation problems.

The Alamo Grazing Allotment is contained within the Monument's upper watersheds (Capulin, Sanchez, and Alamo Canyons). Prior to the Dome Fire, the Alamo allotment was managed under a three pasture deferred rotation grazing system where 66 head of mother cows and about 60 calves graze from June 1 to October 30. Surveys noted the allotment condition ranged from high to fair in the upper allotment, to poor in the lower areas. Cattle grazing typically occurs a few miles upstream from Bandelier's boundaries, is of relatively low density, and canyon bottoms are reported little used and mostly fenced off (Allen, pers. comm., Bandelier National Monument, 1998). Livestock were not allowed to graze during the 1996 grazing season due to the Dome Fire and associated emergency rehabilitation efforts. The potential affects of future grazing were assessed by the USFS (Cassidy et al., 1996), and livestock are again permitted on the Alamo allotment.

The Elk Meadows subdivision straddles the upper drainage of Alamo Creek but is over 5 miles upstream from Bandelier's boundary. Current, low-levels of development are unlikely to be causing detectable water quality impairment within Alamo Canyon at the Monument boundary. Elk Meadows was only lightly developed when the NPS acquired it in 1999. Federal acquisition will keep this area from becoming a further source of external impacts.

Recommendation: The main question from Bandelier's staff concerning external impacts was whether or not water resource monitoring should be conducted to assess upstream impacts. At this time, initiation of a water quality, substrate, or geomorphic monitoring program to quantify external impacts is not recommended. Because the Los Utes timber sale, and more notably, the Dome Fire have already affected headwater areas, stream channels and water quality are currently in a state of recovery. If a specific extraction proposal, such as timber salvage operations, is put forth, baseline stream assessments should probably be conducted at that time, depending on the nature and scale of the project

It is important for Bandelier to continue to negotiations with the USFS to encourage adherence to the enabling legislation by treating the upper watersheds in such a manner as to adequately protect water resources, both within the Forest and on the downstream Monument. This is especially important in light of the fact that the NPS may acquire these lands in the future. Likewise, steps intended to block private development in the upper watersheds should also be completed.

Ungulates

Ungulates (hoofed animals) can negatively impact water resources by direct fecal contamination, destruction of streamside and riparian vegetation, trampling stream banks, promoting erosion in the watershed, and destabilizing geomorphic processes. Such problems only develop when animal numbers exceed the carrying capacity of the landscape, or if they concentrate in stream or riparian environs. At Bandelier, watershed impacts appear to be the major concern because much of the landscape is highly erodible. Concentration of animals along streams or within riparian areas may be a problem at higher elevations.

Livestock "have been a significant perturbation to natural ecosystems within the current park boundaries since the 1880s" (Allen 1989a). The grazing is considered to be a significant factor in the piñon-juniper zone's poor and declining vegetation and soil conditions. Within riparian areas and along the Rio Grande, trespass livestock destabilize stream banks, eat and trample desirable vegetation, and spread non-native plants. Along the Rio Grande, these concerns were muted by the creation of Cochiti Reservoir. Livestock (cattle and feral burros) have been removed from the Monument, but occasionally trespass along the Rio Grande and within lower canyon reaches and upper headwaters. Livestock grazing has resumed on adjacent Santa Fe National Forest lands in the upper Alamo and Capulin watersheds. In addition the USFS has decided to use the Dome Allotment as a spillover for other allotments that need to be relieved of animals.

Population surveys indicate increased numbers of elk and deer, and show elk continuing to colonize lower elevation sites in increasing numbers (National Park Service, 1995a). Considering the severe erosion problems that exist at Bandelier, managers are justifiably concerned that increased elk populations will exacerbate erosion. Moist meadows and small headwaters streams at higher elevation in the Monument are apparently being degraded by heavy elk use as well (National Park Service, 1995a).

Recommendation: The E (summarized as low gradient and meandering) and B (fast flowing and constrained) stream types found in the upper elevations of Bandelier are geomorphicly stable (Rosgen, 1996). Elk concentration would have to be high for direct physical impacts to these stream types to become measurable. Overgrazing of streamside vegetation and changes in riparian community structure are typically the first chronic indications of elevated ungulate populations. At Bandelier, willow-lined stream banks, common in other western riparian areas, were not generally observed. Either these have been effectively eliminated or never occurred.

Bandelier is in the process of conducting a comprehensive elk impact research project that includes elk exclosures (Fettig, pers. comm., Bandelier National Monument, 1998). It might be informative to place an exclosure within a riparian area and determine the vegetative response. It would also be of interest to seek out areas of the Jemez Mountains with little ungulate usage (if such an area exists) and conduct background vegetation collections to reference Bandelier's high elevation stream zones against.

In general, the ongoing effort by the park to exclude livestock and monitor and interpret the impacts of native ungulates is the preferred alternative.

Water Rights

New Mexico water law follows the doctrine of prior appropriation. The right to use water is established by placing it to beneficial use and is maintained as long as water use continues. Rights established earlier in time are senior to, and must be satisfied before, those rights established later. State law requires a permit for any water use other than small domestic or stock wells or small stock reservoirs. Bandelier has two prior appropriation water rights. License number 820 allows diversion of 45 acre-feet from Frijoles Creek to irrigate an historic

orchard in Frijoles Canyon with a 1915 priority date. License number 2470 allows diversion of 11 acre-feet from Frijoles Creek for domestic uses with a priority date of 1943. Previous reference has been made to a well drilled in 1950 (Pettee, 1996; Purtymun and Adams, 1980), but the existence of this well could not be verified as part of this work.

The United States Supreme Court has ruled that, when the government reserves land for specific purposes, it also reserves an amount of water, from that amount unappropriated at the time of the reservation, to fulfill the purposes of the reservation. These rights associated with federal reservations vest, or have a priority date as of the time of the reservation. Consistent with this legal interpretation, there exists a federal reserved water right for consumptive uses and instream uses at Bandelier with a priority date that is the proclamation date, 1916. The quantity of this reserved water right is undetermined until such time as the United States brings a court action or is joined in a McCarran adjudication (43 USC 666). Neither of these actions is anticipated at this time.

Currently, all potable water used at the Monument is supplied by the County of Los Alamos. Irrigation of the historic orchard has occurred only sporadically since the 1970s (Stephens, 1982). Park managers currently feel that the orchard is not a central theme within the cultural arena and its maintenance would require an inordinate amount of effort (final decision pending review of historic significance of the orchard). Natural flow regimes in park streams and springs are critical for many instream and riparian resources such as fish, macroinvertebrates, riparian vegetation, etc. In turn, these instream aquatic resources support many species of mammals and birds. Additionally, a free flowing stream is important to interpreting the cultural resources of Bandelier because a source of water was a critical element to human inhabitation of the canyon.

Past irrigation practices have impacted natural resources within the Monument. The diversion ditch extended upstream through 2,000 feet of the Frijoles Creek riparian zone and canyon bottom. In addition to the direct impacts of this ditch and its maintenance, leakage from the ditch can create unnatural wet areas and even alter alluvial ground water elevations and flow directions, skewing plant and animal communities. Also, maintenance of diversion head gate structures typically requires manipulation of the natural stream channel. Finally, diverting water exasperates impacts to the in-channel aquatic resources. As an example, the minimum stream flow (excluding freezeup periods) recorded on Frijoles Creek during the 6-year gauging record (1963 to 1969) was 0.04 cubic feet per second on July 22, 1966, and the USGS indicates this low-flow was a "result of regulation" (USGS 1966).

Natural protection for instream flow is generally available because most Frijoles Creek watershed is contained within the Monument boundaries. Diversion from Frijoles or any tributaries within the Monument could be controlled through surface management actions. There are small areas of private and National Forest lands in upper Alamo and Capulin canyons where water could be diverted. However, such diversions would have to be very small (stock water and domestic) or are unlikely because surface water in the Rio Grande basin is fully appropriated. If an application for a major diversion was made, the park could rely on its reserved and prior appropriation rights to protect resources.

Recommendation: Bandelier should reconcile its future water needs with existing water rights to determine if additional rights should be secured or if any existing rights are not needed. Water rights are real property and must be managed accordingly. Options for adjusting park water rights to meet water use needs include acquisition, transfer, lease, sale, and exchange. The Water Resource Division's Water Rights Branch is available to assist the park with this project.

Extraordinary Resource Waters Designation

Rosenlieb (1998) has been reviewing and commenting on revised surface water standards for the State of New Mexico on behalf of the National Park Service. In his initial review, Rosenlieb presented comments to the New Mexico Environmental Office and the U.S. Environmental Protection Agency concerning the lack of a nominating process for Outstanding National Resource Waters within New Mexico. Outstanding National Resource Waters (ONRW) can be an important designation for in-park waters because it provides the highest level of water quality protection within most state hierarchies. Many states link an antidegradation policy to ONRW designation that mandates no reduction of existing water quality. This is especially important where upstream, non-park, water quality impairment is likely or ongoing. Outstanding National Resource Water designation can also place additional compliance responsibilities on park management. For example, the physical impairment, sediment loading, and embeddedness within Rito de los Frijoles at Monument headquarters could well be viewed as a violation of the antidegradation clause under ONRW standards.

The process for nominating ONRW waterbodies has been identified by NMED and includes the following steps (Rosenlieb, 1998):

1. A map of the surface waters of the state, including the location and proposed upstream and downstream boundaries;
2. A written statement in support of the nomination, including specific reference to the applicable criteria for ONRW;
3. Supporting evidence demonstrating that one or more of the applicable ONRW criteria listed in Section 1101.c of the Part has been met;
4. Water quality data to establish a baseline for the proposed ONRW,
5. A discussion of activities that might contribute to the reduction of water quality in the proposed ONRW; and,
6. Any additional evidence to substantiate such a designation.

The NMED Commission and possibly the New Mexico legislature still must approve the proposed nomination procedure. Therefore, final procedures are not expected to be put forth any sooner than late spring 1999 (Rosenlieb, 1998).

Recommendations: Bandelier should pursue ONRW designation for Alamo and Capulin Creeks. This would help protect these streams from upstream water quality impairment and lend additional weight to Bandelier's argument that fire management efforts in the watersheds should be implemented to protect these streams. This effort could be done in a cooperative manner through a technical assistance request to the Water Resources Division. The ONRW nomination

package could be forwarded to the State along with nominations from other parks in New Mexico.

A recommendation regarding Frijoles Creek will require additional management consideration. ONRW designation could benefit Frijoles in several ways: 1) NMED might assess potential LANL contaminant migration more seriously and might get more directly involved with monitoring and protecting Frijoles; 2) LANL would have additional justification for characterizing and monitoring potential ground water and contaminant migration into Frijoles Creek; and, 3) it could help justify funding and support for sewage system upgrades, efforts to restore the degraded headquarters stream reach, watershed restoration, further cooperative efforts with the state to assess the impacts of non-native species, and the determination of appropriate action with regard to DDT levels in fish.

This designation could also put significant external pressure on the park to address habitat damage near the picnic area. Managers may want to rectify this situation before proceeding with nomination. The NPS would also not be allowed to discharge treated sewage to ONRW streams. It is unknown how storm water runoff from the headquarters parking, maintenance, and office facilities would be viewed under this designation within New Mexico.

See Appendix D for ONRW associated project statement.

Water Quality Monitoring

Bandelier's Resource Management Plan states that "Bandelier cannot properly manage its riparian habitat, nor assess impacts from park operations and adjacent land use without a credible water quality monitoring program. In contrast to the park-wide baseline monitoring approach previously used, the new monitoring program would address specific management concerns with discrete, well-designed monitoring efforts of limited duration (National Park Service, 1995a)."

Recommendation: Specific studies are important in dealing with recognized water resource issues. However, only long-term, Monument-wide, water resource monitoring, research, and study integration will develop a holistic understanding of this NPS unit's water resources. Because Bandelier does not have a water resource specialist on staff, it is agreed that focused studies by individually qualified specialists are the best way to meet identified water resource concerns. Specific water resource topics that could be developed into project statements include:

- Further physical and biological assessment of the headquarters reach of Frijoles Creek to be used in justifying and developing a restoration program;
- Impacts of exotic trout and feasibility of using a shocking program to (re)introduce native cutthroat;
- Assessment of sewage infrastructure for potential leaks;
- Assessment of fish consumption ban;
- Assessment of potential for groundwater transport from LANL to Frijoles;
- Refinement of temporal and spatial trends of fecal coliform bacteria in Frijoles at Monument headquarters; and,
- Assessment of the potential for land sliding and overbank flooding.

Recreation

Overnight stays in the wilderness account for only about one percent (3,820 visitors) of total visitation each year. Wilderness day-hikers comprise a larger but undocumented percentage. Wilderness visitors use surface water for bathing, swimming, and drinking, particularly during the summer months. Horse travel is allowed in some wilderness areas. Improper disposal of human waste in streams or riparian areas, coupled with runoff of horse manure at stream crossings and from holding areas, could elevate nutrient and coliform concentrations in streams (National Park Service, 1995a).

Past monitoring indicated the horse corral at headquarters was a source of bacterial input during runoff events. The Frijoles corral boards seven to eight horses for approximately nine months each year (Stevens, 1996). Redesign of the corral and corral area drainage, plus more intensive horse and manure management, appears to have alleviated this problem. Water quality monitoring conducted by Monument staff at various backcountry stations on Capulin, Alamo, and Frijoles Creeks did not detect recreational impairment of water quality.

Wilderness use, especially in the non-NPS headwater areas, could increase with the 1993 establishment of the Jemez Mountains National Recreation Area within the Santa Fe National Forest (Public Law 103-104). Off-road-vehicle users have expressed a great deal of interest in this recreation area and this special designation should bring money and attention to the lands adjacent to Bandelier's western boundary. Route 289, also called Dome Road (Figure 9), may be graded and graveled or paved due to public pressure on the USFS so that average vehicles can access the Recreation Area most of the year.

Flood plain delineation in backcountry areas is not required by NPS regulations. Instead, permit procedures, visitor center contacts, and information brochures, are used to provide flood warning information to visitors traveling in these areas.

Recommendation: The dispersed nature of the trail system combined with moderate levels of wilderness visitation, permit systems, zoning, and other management and educational efforts, appears to be keeping concentrated use of specific backcountry areas to a minimum. The most intensively used front-country riparian area is Frijoles Canyon above and at Monument headquarters. Capulin Canyon is the most intensively used wilderness riparian area. Recreational impacts could be inferred for the Monument by monitoring on Frijoles and Capulin creeks below the high use areas, and extrapolation the results to other areas.

Road Salting

During winter conditions, the New Mexico Department of Transportation applies road salt and cinders to Highway 4 within the upper Frijoles watershed (Figure 9). Studies in New Mexico conducted by Gosz (1977) showed runoff containing sodium chloride is mobile, rapidly contaminates ground water, and is toxic to most vegetation. Sodium infiltration into soils caused the release of other cations and significantly altered soil structure in downstream areas. The breakdown of soil structure appeared to be the major reason for large losses of sediment and

heavy metals from areas below roads. Steep slopes and a large road area to below road ratio appear most influential in altering water quality (Gosz, 1977).

Kunkle (pers. comm., Santa Fe, NM, 1999) studied road salt migration into the environment and found sodium and chloride moving readily into the ground. Much of the salt washed off during snow melt, as would be expected, but sodium, chloride, and conductivity were also higher during baseflow periods during summer when the contaminated soil and ground water discharged to the stream. It is probable that soil contamination is occurring because plant mortality is noted in the salting areas, especially mortality of ponderosa pine (Sydoriak, pers. comm., Bandelier National Monument, 1999).

Recommendation: Bandelier should take conductivity readings from road ditches and rivulets above and below Highway 4 during snow melt conditions. Initial conductance screening would show if below road samples have elevated levels of dissolved ions (sodium and chloride). If conductance is measurably higher below road areas, further sampling could follow to quantify sodium and chloride increases, this would include similar conductance screening during baseflow conditions for the reason stated above. Vegetation should also be examined in areas showing elevated conductance values. If warranted, results could be provided to the New Mexico Highway and Transportation Department with an accompanying request to minimize or eliminate road salt use in the Frijoles headwaters area.

See Appendix D for Road Salting associated project statement.

Atmospheric Deposition

The Bandelier Wilderness is a designated "Class I" airshed under the Clean Air Act and Amendments. The historical trends in visibility indicate that air pollution has contributed to a general decline in visual range over the last several decades, probably due in large part to the growth of the surrounding urban areas. On the Colorado Plateau, fine sulfate particles are responsible for 40 to 60 percent of the visibility impairment. Sulfate particles are primarily the result of human produced sulfur oxide emissions (National Park Service, 1995a). Acid rain is also a potential concern with 50 percent of the acids in the region's rain generally sulfuric acids. Sulfuric acid-gases emitted into the air are primarily from fossil fuel combustion in power plants, industry, and motor vehicles (Stephens, 1982).

Atmospheric deposition has been monitored at Bandelier since 1982 as part of the National Atmospheric Deposition Program (Figure 30). Yearly averages for nitrates, pH, and conductance show no clear trend between 1982 and 1997, while sulfate shows a statistically significant downward trend. This analysis suggests that Bandelier's water resources are not being impacted by atmospheric deposition which is more acidic or measurably elevated in nutrients or other major ions.

Recommendation: Bandelier should continue monitoring atmospheric deposition as part of the National Atmospheric Deposition Program so that any future changes in rain chemistry might be detected.

Figure 30. Bandelier National Monument Atmospheric Precipitation Yearly Averages with Trend Line Plotted for Sulfate (National Atmospheric Deposition Program Data).

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APPENDIX A

Rapid Physical Habitat Assessment Data for Frijoles Creek at Monument Headquarters

Frijoles Creek at Monument Headquarters
Baseline Physical Assessment, Picnic Access Area
Bankful Stage Interpreted to be 2.1 to 2.4 feet at USGS Gauge --- Between 5 and 19 cfs
Anomalously Low Bankful Stage Compared to Regional Curves as Presented by Rosgen

Bandelier National Monument, New Mexico
July 7, 1998
Field Team: David Mott, Brian Jacobs, David Vana-Miller
Data Reduction and Interpretation by David Mott

ALL UNITS IN FEET EXCEPT SUBSTRATE IS CENTIMETERS

Station	Distance*	Bankful Width	Avg B.F. Depth	W/D Ratio	Approx. B.F. Area	Flood Prone Width	Entrenchment Ratio	Stream Type (Rosgen)	% Cover R. Bank	% Cover L.Bank	Average % Cover	Least % Cover	Embeddedness Ratio - In/Out	Avg. Size Substrate
1	25	4.75	0.66	7.20	3.14	16	3.37	C	100	100	100	100	1	1.55
2	75	4.65	0.75	6.20	3.49	14.3	3.08	C	100	100	100	100		0.4
3	125	4.75	0.75	6.33	3.56	12	2.53	B	100	100	100	100	0.285714286	11.6
4	175	5.75	1.33	4.32	7.65	20	3.48	C	100	100	100	100	0.5	3.3
5	225	7.35	1.05	7.00	7.72	13.65	1.86	B	100	100	100	100	0.5	10.5
6	275	8.35	0.95	8.79	7.93	19.25	2.31	C	100	90	95	90	1	12.9
7	325	9.15	0.8	11.44	7.32	12.5	1.37	F	100	100	100	100	0.235294118	1.75
8	375	3.85	1	3.85	3.85	6.45	1.68	B	100	95	97.5	95		0.33
9	425	6.75	0.8	8.44	5.40	10	1.48	B	100	90	95	90	0.5	2.7
10	475	6.5	0.7	9.29	4.55	10.35	1.59	B	100	97	98.5	97	1	2
11	525	6.75	0.63	10.71	4 25	11.5	1.70	B	100	100	100	100	0.588235294	3.4
12	575	7.15	0.75	9.53	5.36	11.5	1.61	B	100	95	97.5	95	0.166666667	11.4
13	625	4.5	0.87	5.17	3.92	7.35	1.63	B	100	99	99.5	99	1.492537313	3
14	675	10	0.66	15.15	6.60	15	1.50	B	100	100	100	100	1	20
15	725	7.25	1.25	5.80	9.06	13.5	1.86	B	98	100	99	98	0.333333333	3.6
16	775	6.75	1.2	5.63	8.10	9	1.33	F	80	90	85	80	3.076923077	6.6
17	825	13.5	1.35	10.00	18.23	23	1.70	B	100	100	100	100	0.714285714	41
18	875	8	0.91	8.79	7.28	16.75	2.09	B	100	80	90	80	0.2	12.3
19	925	9.35	0.88	10.63	8.23	19.25	2.06	B	100	90	95	90		0.5
20	975	10	0.83	12.05	8.30	14.85	1.49	B	100	100	100	100	0.277777778	4.1
21	1025	9.45	0.96	9.84	9.07	16.35	1.73	B	60	90	75	60	1.666666667	12
22	1075	9.75	0.63	15.48	6.14	16.75	1.72	B	100	100	100	100		1.7
23	1125	8.15	1.1	7.41	8.97	17	2.09	B	100	98	99	98	0.333333333	25
24	1175	9.7	0.66	14.70	6.40	17	1.75	B	95	95	95	95	1.666666667	2.75
25	1225	8.35	1.25	6.68	10.44	21	2.51	C	95	100	97.5	95		0.2
26	1275	5.25	1.5	3.50	7.88	11.5	2.19	B	100	100	100	100		0.2
27	1325	7.75	1.1	7.05	8.53	18.5	2.39	C	100	100	100	100	1	7.7
28	1375	18.8	0.83	22.65	15.60	22	1.17	F	98	100	99	98		0.15
29	1425	16.1	0.83	19.40	13.36	21.5	1.34	F	20	50	35	20		0.05
30	1475	12.5	0.5	25.00	6.25	16.35	1.31	F	90	80	85	80		0.05
31	1525	8.75	1.4	6.25	12.25	20	2.29	C	100	60	80	60		0.2
32	1575	7.5	1.3	5.77	9.75	11.75	1.57	B	10	60	35	10		0.2
33	1625	4.9	0.9	5.44	4.41	7.75	1.58	B	75	70	72.5	70	0.111111111	2.1
34	1675	10	0.6	16.67	6.00	11.45	1.15	F	20	10	15	10		1.9
35	1725	14.95	1.3	11.50	19.44	14.92	1.00	F	20	20	20	20		0.15
36	1775	10.5	0.92	11.41	9.66	10.85	1.03	F	2	15	8.5	2		0.3
37	1825	12.6	0.46	27.39	5.80	14.34	1.14	F	20	50	35	20	1	0.95
38	1875	10.45	0.75	13.93	7.84	11.75	1.12	F	7	15	11	7		0.8
39	1925	9.85	0.67	14.70	6.60	13.25	1.35	F	5	20	12.5	5	5	4.3
		Bankful	Avg B.F.	W/D	Approx.	Flood Prone	Entrenchment	Stream Type	% Cover	% Cover	Average	Least	Embeddedness	Avg. Size

Station	Distance*	Width	Depth	Ratio	B.F. Area	Width	Ratio	(Rosgen)	R. Bank	L.Bank	% Cover	% Cover	Ratio - In/Out	Substrate
40	1975	18.6	1.25	14.88	23.25	19.65	1.06	F	15	25	20	15	0.125	7
41	2025	9.6	0.58	16.55	5.57	10	1.04	F	30	30	30	30		0.05
42	2075	9.7	0.42	23.10	4.07	11.4	1.18	F	5	5	5	5		0.15
43	2125	10.25	0.67	15.30	6.87	11.15	1.09	F	10	10	10	10	0.588235294	5.5
44	2175	13.75	0.54	25.46	7.43	15.75	1.15	F	10	10	10	10	0.2	2.2
45	2225	10	0.63	15.87	6.30	13.25	1.33	F	40	80	60	40	3.333333333	5
46	2275	11.85	0.67	17.69	7.94	12.45	1.05	F	5	90	47.5	5	0.166666667	11.5
47	2325	9.75	0.7	13.93	6.83	14	1.44	F	15	80	47.5	15	0.166666667	4
48	2375	8	0.5	16.00	4.00	9.45	1.18	F	35	90	62.5	35		0.22
49	2425	12	0.67	17.91	8.04	14.35	1.20	F	10	15	12.5	10		0.1
50	2475	10.75	0.8	13.44	8.60	15.67	1.46	F	40	35	37.5	35		0.2
51	2525	8.5	1.1	7.73	9.35	11.25	1.32	F	85	90	87.5	85	0.588235294	3.4
52	2575	12.5	0.92	13.59	11.50	18.4	1.47	F	20	80	50	20		0.15
53	2625	10	0.92	10.87	9.20	19.5	1.95	B	50	60	55	50	1	4.5
54	2675	11	0.7	15.71	7.70	16.85	1.53	B	20	20	20	20		0.1
55	2725	5.35	1	5.35	5.35	9	1.68	B	10	45	27.5	10		0.2
56	2775	6.8	0.83	8.19	5.64	12.75	1.88	B	95	95	95	95	0.625	22
57	2825	5.45	0.67	8.13	3.65	7	1.28	F	85	90	87.5	85	0.625	10
58	2875	.8.4	0.58	14.48	4.87	16.75	1.99	B	80	85	82.5	80	0.149253731	18
59	2925	10.3	0.67	15.37	6.90	18.75	1.82	B	70	85	77.5	70	0.5	2.2
60	2975	5	0.92	5.43	4.60	13	2.60	C	85	45	65	45	0.666666667	1.3
61	3025	7.25	0.71	10.21	5.15	13	1.79	B	95	95	95	95	1.25	7.75
62	3075	5.85	1.2	4.88	7.02	14.5	2.48	C	85	90	87.5	85	0.4	3.1
63	3125	8.3	1.4	5.93	11.62	13.85	1.67	B	85	85	85	85	0.5	1.05

* Stream Length = 3150
*Valley Length = 2500
* Sinuosity = 1.26
* Gradient = 50 ft / 3150 ft = 0.016
* Above measurements from large scale map with 10 ft contour interval

*Distance is given upstream relative to horse trail crossing
* Embeddedness ratio not calculated for cross-section dominated by bedrock or fines
*Downstream road loop between station 15 and 16
*USGS gauge between 17 and 18
*First pedestrian bridge at station 29
*Road bridge at 35
*Washed out bridge at station 40
*Forgot to note other bridges
*End of road at 54 and end of picnic area at 55
* Social trail at 58

APPENDIX B

Federal Acts, Regulations and Policies Specific to Administration of National Park Units

There are four laws that constitute the primary authorities for administration of the National Park System.

National Park Service Organic Act (1916)

In the 1916 Congress created the National Park Service in the Department of the Interior to:

> promote and regulate the use of the Federal areas known as national parks, monuments, and reservations . . . by such means and measures as conform to the fundamental purpose of said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations. (NPS organic act, 16 USC 1)

The basis for park management policies was specifically addressed for the first time by Secretary of the Interior Franklin K. Lane in a letter to the first director of the National Park Service, Stephen T. Mather, on May 13, 1918, Secretary Lane stated that administrative policy should be based on three broad principles:

First, that the national parks must be maintained in absolutely unimpaired form for the use of future generations as well as those of our own time; second, that they are set apart for the use, observation, health, and pleasure of the people; and third, that the national interest must dictate all decisions affecting public or private enterprise in the parks.

National Environmental Policy Act (1969)

This law requires a systematic analysis of federal actions with the potential to affect the human and natural environments. The analysis includes a consideration of reasonable alternatives and an analysis of short- and long-term irretrievable, irreversible, and unavoidable impacts. If a federal action may result in major impacts, an environmental impact statement is prepared. The EIS ensures evaluation of the impacts of proposed projects and facilitates public review.

Regulations implementing NEPA require the cooperation of federal agencies and encourage the reduction of duplication through cooperation with state and local agencies including early efforts of joint planning, hearings and environmental assessments.

General Authorities Act (1970)

The General Authorities Act of 1970 defines the national park system as including "any area of land and water now or hereafter administered by the Secretary of the Interior through the National Park Service for park, monument, historic, parkway, recreational, or other purposes" (16 USC lc(a)). It states that "each area within the national park system shall be administered in accordance with the provisions of any statute made specifically applicable to that area" (16 USC lc(b)) and in addition with the various authorities relating generally to NPS areas, providing the general legislation does not conflict with specific provisions.

Redwood National Park Act (1978)
In a 1978 act expanding Redwood National Park, NPS general authorities were further amended to add:

The authorization of activities shall be construed and the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress. (16 USC la-l)

Other Federal Acts Relevant to Federal Land Management

Clean Water Act

The Federal Water Pollution Control Act, more commonly known as the Clean Water Act, was first promulgated in 1972 and amended in 1977, 1987, and 1990. This law was designed to restore and maintain the integrity of the nation's water. Goals set by the act were swimmable and fishable waters by 1983 and no further discharge of pollutants into the nation's waterways by 1985. The two strategies for achieving these goals were a major grant program to assist in the construction of municipal sewage treatment facilities and a program of "effluent limitations" designed to limit the amount of pollutants that could be discharged.

As part of the act, Congress recognized the primary role of the states in managing and regulating the nation's water quality within the general framework developed by Congress. All federal agencies must comply with the requirements of state law for water quality management, regardless of other jurisdictional status or land ownership (section 313). States implement the protection of water quality under the authority granted by the Clean Water Act through best management practices and through water quality standards. Best management practices are defined by the U.S. Environmental Protection Agency (EPA) as methods, measures, or practices selected by an agency to meet its nonpoint control needs. These practices include but are not limited to structural and non-structural controls, operational procedures, and maintenance procedures. They can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters (Code of Federal Regulations 1990). Water quality standards are composed of the designated use or uses made of a water body or segment, water quality criteria necessary to protect those uses, and an anti-degradation provision to protect the existing water quality.

Section 404 of the Clean Water Act further requires that a permit be issued for discharge of dredged or fill materials in waters of the United States including wetlands. The Army Corps of Engineers administers the Section 404 permit program with oversight and veto powers held by the EPA.

Clean Water Act and regulations are generally implemented by the states with the EPA serving in an oversight role. A triennial review of a state's water quality regulatory program is conducted

by each state's water quality agency to determine if its standards are adequate to meet federal requirements. These standards are then forwarded to the EPA for approval.

Rivers and Harbors Appropriations Act of 1899, as amended (33 U.S.C. 401-466n)

This was the first general legislation giving the Corps of Engineers jurisdiction and authority over the protection of navigable waters. Under it, permits from the Department of the Army are required for structures and/or work in or affecting navigable waters of the United States (33 CFR 322.3(a)). Regulation of activities under the Rivers and Harbors Act is often, though not always, used in concert with regulation under Section 404 of the Clean Water Act. Rivers and Harbors Act jurisdiction is not limited to activities in navigable waters but also includes any actions that "affect" those waters. (33 CFR 322.3(a)) The Corps is allowed broad discretion in making this determination. Jurisdiction of the Corps of Engineers over navigable waters reaches laterally to the ordinary high water mark in freshwater areas (33 CFR 329.11(a)). Also, it has been determined that jurisdiction extends to an area over which a river customarily flows from time to time in its natural meanderings (Want 1996). If there is a possibility that an action in a park could affect navigable waters, park staff should: (1) contact the local Corps office to determine if there are navigable waters in the park, and (2) if there are, determine the requirements for obtaining a permit. Activities which often require a permit include: piers, ramps or docks; transmission lines, cables or pipes over, under or through the water; jetties, bulkheads, revetments. or breakwaters; water withdrawals; etc. (Bridges require Coast Guard authorization under a section 9 permit).

Floodplain Management (Executive Order 11988, 1977)

The objective of this executive order is to require agencies to "reduce the risk of flood loss, ... minimize the impacts of floods on human safety, health and welfare, and... restore and preserve the natural and beneficial values created by floodplains" (Goldfarb 1988). Federal agencies are therefore required to implement floodplain planning to avoid to the extent possible the long- and short-term adverse impacts associated with occupancy and modification of floodplains. Agencies are also to avoid direct and indirect support of floodplain development wherever there is a practicable alternative. National Park Service guidance pertaining to Executive Order 11988 can be found in Floodplain Management Guidelines (National Park Service 1993) which supersedes the Floodplain portion of the NPS Floodplain and Wetland Management Guidelines of 1980.

Protection of Wetlands (Executive Order 11990, 1977)

This executive order requires all federal agencies to "minimize the destruction, loss or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands" (Goldfarb 1988). This order furthers the purposes of the National Environmental Policy Act by directing federal agencies to avoid to the extent possible the long- and short-term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or indirect support of new construction in wetlands when practicable alternatives exist. National Park Service guidance for compliance with E. O. 11990 can be found in Director's Order 77-1

and Procedural Manual 77-1, "Wetlands Protection". Particularly, it is the policy of the National Park Service to:

- Avoid to the extent possible the long- and short-term impacts associated with destruction or modification of wetlands;
- Preserve and enhance the natural and beneficial values of wetlands;
- Avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative;
- Adopt a goal of "no net loss of wetlands" and strive to achieve a longer-term goal of net gain of wetlands Servicewide;
- Conduct or obtain parkwide wetland inventories to help assure proper planning with respect to management and protection of wetland resources;
- Use "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin et al. 1979) as the standard for defining, classifying, and inventorying wetlands;
- Employ a sequence of first avoiding adverse wetland impacts to the extent practicable; second, minimizing impacts that could not be avoided; and , lastly compensating for remaining unavoidable adverse wetland impacts at a minimum 1:1 ration via restoration of degraded wetlands;
- Prepare a Statement of Findings to document compliance with Director's Order 77-1 when the preferred alternative addressed in an environmental assessment or environmental impact statement will result in adverse impacts on wetlands; and,
- Restore natural wetland characteristics or functions that have been degraded or lost due to previous or ongoing human activities, to the extent appropriate and practicable.

National Park Service Management Policies and Guidelines

The National Park Service Management Policies (1988) give broad policy guidance for the management of National Park System Units. Some of the topics included are: park planning, land protection, natural and cultural resource management, wilderness preservation and management, interpretation and education, special uses of the parks, park facilities design, and concessions management. Recommended procedures for the implementation of service-wide policy are described in the NPS guideline series. Guidelines most directly related to actions affecting water resources include: 1) Director's Order 2, Planning Process; 2) Director's Order 12 (draft), for compliance with National Environmental Policy Act; 3) NPS-75, for Natural Resources Inventory and Monitoring, 4) NPS-77, for Natural Resource Management, and 5) Director's Order 83, Public Health Management.

Some aspects of water resources will be important considerations in a General Management Plan because it is the primary planning tool for making decisions about land use in the park, including the placement of facilities. The occurrence of flood hazards and wetlands will influence these decisions, because the NPS policy is to first avoid conflicts with these resources, by identifying sensitive areas, and not locating facilities in them. If facilities must be located in wetlands or floodplains (boat launch ramps, for example, must be located in floodplains), a Statement of Findings is required to document the necessity of using that particular location. The state designation of major portions of the Riverway as Outstanding Resource Waters, will also

influence facility location and design, because wastewater discharge permits will be difficult, if not impossible, to obtain.

Endangered Species Act (1973)

This act provides for the conservation, protection, restoration, and propagation of selected species of native fish and wildlife that are threatened with extinction. All federal agencies must consult with the Secretary of the Interior on activities that potentially effect endangered flora and fauna.

Section 7 outlines procedures for interagency cooperation to conserve federally listed species, species proposed for listing and for designated critical habitat and proposed critical habitat. Section 7(a)(1) requires federal agencies to use their authorities to further the conservation of listed species and section 7(a)(2) prohibits federal agencies from undertaking, funding, permitting or otherwise authorizing actions that are likely to jeopardize the continued existence of listed species or that would destroy or adversely modify critical habitat.

Water Quality Improvement Act (1970)

This act requires federally regulated activities to have state certification that they will not violate water quality standards.

Safe Drinking Water Act (1974) and Amendments (1986)

This act sets national water quality standards and requires regular testing of drinking water for developed public drinking water supplies.

APPENDIX C

Pertinent Information Relevant to Protected and Sensitive Species

SPECIES	FEDERAL STATUS/ SPECIES OF CONCERN	STATE STATUS	HABITAT NEEDS	COMMENTS
ANIMAL SPECIES				
American Peregrine Falcon (*Falco peregrinus anatum*)	Endangered	Threatened	• Uses the juniper savannah, pinyon-juniper woodland, ponderosa pine forest, and mixed-conifer forest vegetation zones • Requires cliffs for nesting	• Forages on LANL. Nests and forages on adjacent lands.
Whooping Crane (*Grus americana*)	Endangered	Endangered	• Requires rivers and marshes • Roosts on sand bars	• Migratory visitor along the Rio Grande and Cochiti Lake
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)	Endangered	Endangered	• Requires riparian areas and vegetation • Requires dense riparian vegetation	• Potential presence on LANL and White Rock Canyon • Potential nesting area on LANL • Present in Jemez Mountains • Present in riparian zone near Espanola
Bald Eagle (*Haliaeetus leucocephalus*)	Threatened	Threatened	• Rivers and lakes	• Observed as a migratory and winter resident along the Rio Grande and on adjacent LANL lands
Mexican Spotted Owl (*Strix occidentalis lucida*)	Threatened	Sensitive (informal)	• Mixed conifer, ponderosa pine • Prefers tall, old-growth forest in canyons and moist areas for breeding • Forages in forests, woodlands, and rocky areas	• Breeding resident on LANL, LAC, BNM, and SFNF lands • Critical habitat designated on SFNF lands
Jemez Mountain Salamander (*Plethodon neomexicanus*)	Species of Concern	Threatened	• Uses the mixed-conifer forest vegetation zone • Requires north-facing, moist slopes	• Permanent resident on LANL, LAC, BNM, and SFNF lands
Baird's Sparrow (*Ammodramus bairdii*)	Species of Concern	Threatened	• Uses the pinyon-juniper woodland, ponderosa pine forest and mixed-conifer forest vegetation zones	• Observed on SFNF lands

SPECIES	FEDERAL STATUS/ SPECIES OF CONCERN	STATE STATUS	HABITAT NEEDS	COMMENTS
Spotted Bat (*Euderma maculatum*)	Species of Concern	Threatened	• Uses the pinyon-juniper woodland, ponderosa pine forest, and spruce-fir forest vegetation zones • Requires riparian areas • Roosts in cliffs near water	• Permanent resident on BNM and SFNF lands • Seasonal resident on LANL
New Mexico Jumping Mouse (*Zapus hudsonius luteus*)	Species of Concern	Threatened	• Uses the mixed-conifer and spruce-fir forest vegetation zones • Requires riparian areas • Requires water nearby	• Permanent resident on LAC and SFNF lands • Overwinters by hibernating
Flathead Chub (*Platygobio gracilis*)	Species of Concern	Unlisted	• Requires access to perennial rivers	• Permanent resident of the Rio Grande between Española and the Cochiti Reservoir
Ferruginous Hawk (*Buteo regalis*)	Species of Concern	Unlisted	• Uses the juniper savannah and pinyon-juniper woodlands vegetation zones	• Observed as a breeding resident on LAC, LANL, BNM, and SFNF lands
Northern Goshawk (*Accipiter gentilis*)	Species of Concern	Sensitive (informal)	• Uses the mixed-conifer, ponderosa pine, spruce-fir forest vegetation zones	• Observed as a breeding resident on LAC, LANL, BNM, and SFNF lands
White-Faced Ibis (*Plegadis chihi*)	Species of Concern	Unlisted	• Requires perennial rivers and marshes	• Summer resident and migratory visitor on the Rio Grande and SFNF lands
Loggerhead Shrike (*Lanius ludovicianus*)	Species of Concern	Unlisted	• Uses the juniper savannah, pinyon-juniper woodland, ponderosa pine forest, and mixed-conifer forest vegetation zones	• Observed on LAC, BNM, and SFNF lands
Big Free-Tailed Bat (*Nyctinomops macrotis*)	Species of Concern	Sensitive (informal)	• Uses the juniper savannah, pinyon-juniper woodland, and ponderosa pine forest, and mixed-conifer forest vegetation zones • Roosts on cliffs	• Migratory visitor on LAC, BNM, and SFNF lands
Fringed Myotis (*Myotis thysanodes*)	Species of Concern	Sensitive (informal)	• Uses the juniper savannah, pinyon juniper woodland, ponderosa pine forest vegetation zones • Roosts in caves and buildings	• Observed on LANL, BNM, and SFNF lands

SPECIES	FEDERAL STATUS/ SPECIES OF CONCERN	STATE STATUS	HABITAT NEEDS	COMMENTS
Long-Eared Myotis (*Myotis evotis*)	Species of Concern	Sensitive (informal)	• Uses the ponderosa pine forest, mixed-conifer, and spruce-fir forests vegetation zones • Roosts in dead ponderosa pine trees	• Summer resident on LANL, BNM, and SFNF lands
Long-Legged Myotis (*Myotis volans*)	Species of Concern	Sensitive (informal)	• Uses the pinyon-juniper woodland, ponderosa pine forest, and mixed-conifer forest vegetation zones • Roosts in dead conifer trees	• Summer resident on LANL, LAC, BNM, and SFNF lands
Small-Footed Myotis (*Myotis ciliolabrum*)	Species of Concern	Sensitive (informal)	• Uses the juniper savannah, pinyon-juniper woodland, ponderosa pine forest, and mixed-conifer forest vegetation zones • Roosts in cliffs and caves	• Observed on LANL, BNM, and SFNF lands • Overwinters by hibernating
Yuma Myotis (*Myotis yumanensis*)	Species of Concern	Sensitive (informal)	• Uses the juniper savannah and pinyon-juniper woodland forest vegetation zones • Roosts in cliffs and caves near water	• Summer resident on LANL, LAC, and SFNF lands
Occult Little Brown Bat (*Myotis lucifugus occultus*)	Species of Concern	Sensitive (informal)	• Uses the pinyon-juniper woodland and ponderosa pine forest vegetation zones • Requires riparian areas • Forages over water	• Observed on SFNF lands
Pale Townsend's Big-Eared Bat *(Plecotus townsendii pallescens)*	Species of Concern	Sensitive (informal)	• Uses the pinyon-juniper woodland, ponderosa pine forest, and mixed-conifer forest vegetation zones • Roosts in caves	• Observed on LANL and BNM lands • Overwinters by hibernating
Goat Peak Pika (*Ochotona princeps nigrescens*)	Species of Concern	Sensitive (informal)	• Uses the mixed-conifer and spruce-fir forests vegetation zones • Requires boulder piles and rockslides	• Observed on LAC and BNM lands

SPECIES	FEDERAL STATUS/ SPECIES OF CONCERN	STATE STATUS	HABITAT NEEDS	COMMENTS
Gray Vireo (*Vireo vicinior*)	Unlisted	Threatened	• Uses riparian areas in the juniper savannah and pinyon-juniper forests vegetation zones	• Observed on LAC, BNM, and SFNF lands
PLANT SPECIES				
Wood Lily (*Lilium philadelphicum L.* var. *andinum* (Nutt.) Ker)	Unlisted	Endangered	• Grows in the ponderosa pine forest, mixed-conifer, and spruce-fir forests vegetation zones • Requires riparian areas	• Observed on LAC, BNM, and SFNF lands
Yellow Lady's Slipper Orchid (*Cyprepedium calceolus L.* var. *Pubescens* (Willd.) Correll)	Unlisted	Endangered	• Requires riparian areas • Grows in the mixed-conifer forest vegetation zones • Requires moist soil	• Observed on BNM lands
Helleborine Orchid (*Epipactis gigantea* Dougl.)	Unlisted	Rare and sensitive	• Requires riparian areas • Grows in the juniper savannah and pinyon-juniper woodland forests vegetation zones • Requires springs, seeps, or other wet areas	• Observed on LAC lands

Note: This listing was developed with information and guidance provided by biologists from LANL; the FWS; the USFS; the NPS; the National Biological Service; the NMDGF; the New Mexico Energy, Minerals, and Natural Resources Department; and the New Mexico Natural Heritage Program, as well as consultations with independent consultants and reviews of the technical literature.

APPENDIX D

Project Statements

Project Statement
BAND-N-007.006

Last Update:	08/01/99	Priority:	0000
Initial Proposal:	08/01/99	Page Number:	0001

Title: Determine Effects of Prescribed Fire on Surface Hydrology

Funding Status: Funded: 0.00 Unfunded: 91.0

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number

Summary

Within Bandelier's semi-arid southwestern environment, preservation of naturally functioning watersheds is dependent on fire management more than any other factor. For example, fire suppression over the last century culminated in two large and intense wildfires, both of which radically altered the hydrology, fluvial geomorphology, instream habitat, and aquatic communities within the Monument's perennial streams. Bandelier's managers now recognize prescribed fire must be utilized to preserve fire-dependent vegetative communities, and concomitant soil stability and infiltration rates. Studies have clearly demonstrated that where natural fire frequencies have been suppressed, the wildfires which subsequently occurred destabilized watersheds to the point where runoff and delivery of sediment to streams increased by orders of magnitude.

Watershed response to fire is a function of the physical properties of the watershed (geology, soils, slopes, aspect, infiltration capacity, vegetative complex, etc.), climate and precipitation, and the size and intensity of the fire. Hydrologic responses to wildfires (peak flow, sedimentation rate, incision, etc.) are mainly a function of fire severity and climactic events following the fire, along with such factors as topography, soils, vegetation structure, stream size and morphology and others (DeBano et al., 1995). The factors listed above combine in a manner such that Bandelier's hydrologic response to fire occurrence is at the extreme end of the scale. To better manage terrestrial, aquatic, and biological resources, Monument managers have established a prescribed fire program designed to restore natural fire frequency, timing, and intensity. While prescribed fire usually has much less hydrologic impact on watersheds because the surface vegetation, litter, and forest floor are only partially burned, within the hydrologically responsive watersheds of Bandelier a clear and quantitative relationship must be developed between prescribed fire activity and the corresponding response of streams.

This proposal will fund the U.S. Geological Survey to implement a fixed-station monitoring study to measure flow, water quality, physical habitat, and biological responses to prescribed fire activity within Bandelier National Monument. The purpose of collecting these data is to interpret the effect of prescribed fire on Bandelier's watershed's and surface water resources. Currently, the fire management program is being conducted without any monitoring of its impacts on water resources. Hydrologic monitoring is critical to insure that proposed and implemented fire management activities are not unduly impacting the water resources of the Monument, a significant concern given past hydrologic response to fires.

Problem Statement

Stream stability, aquatic habitat integrity, and watershed condition are interdependent. Streams draining a landscape are stable (naturally functioning) when the water and sediment delivery is balanced with the stream's ability to assimilate and transport these loads. Inputs of water and sediment in excess of the stream's assimilative/transport capacity will result in channel destabilization as previously observed at Bandelier during post-wildfire periods. Stream destabilization negatively impacts aquatic and riparian habitat, disrupting natural communities for long periods of time and over extensive stream lengths.

Bandelier's past emphasis on fire suppression ultimately resulted in two widespread, intense, wildfires, the La Mesa Fire in 1977 and the Dome Fire in 1996. The flooding and sediment delivery that ensued exceeded the assimilative capacity of Monument streams and aquatic habitat and communities were degraded. To understand the importance of fire and vegetative management to Bandelier's watersheds and water resources, the following discussion of Bandelier's hydrologic response to fire is provided.

Background

One of the principal streams at Bandelier is Frijoles Creek, a 15-mile long perennial stream that is also regionally significant within the desert southwest. Frijoles drains highly permeable volcanic tuff deposits forming the Pajarito Plateau. The Plateau's high permeability and evapotranspiration cause Frijoles Creek's average annual flow to be an order of magnitude less than regional predictions (Leopold, 1994). Frijoles Creek is also characterized by unusually reduced peak flows, and their dampened nature also reflects the watershed's ability to "act like a sponge" (Kearl et al., 1986).

Measurements which highlight how unusually low maximum discharges are in Frijoles Creek include recurrence interval, discharge, and drainage area relationships provided by Leopold (1994) for the Rio Grande basin. The return interval of 2.33 years for Frijoles Creek's 17.5 mi^2 watershed should exceed 100 cfs, while a ten-year event should exceed 200 cfs. In contrast, the highest observed maximum flow in Frijoles Canyon over the six-year pre-fire reporting period was only 19 cfs. Similarly, the highest pre-fire peak flow observed over nine years of monitoring in Capulin Creek was only slightly greater than 21.8 cfs.

The runoff characteristics of both the Frijoles and the nearby Capulin basins changed radically as a result of the 1977 La Mesa Fire, and the 1996 Dome Fire, respectively. As displayed in Figure 1 (note y-axis is logarithmic), post-burn stream-flow records exhibit distinct changes in both

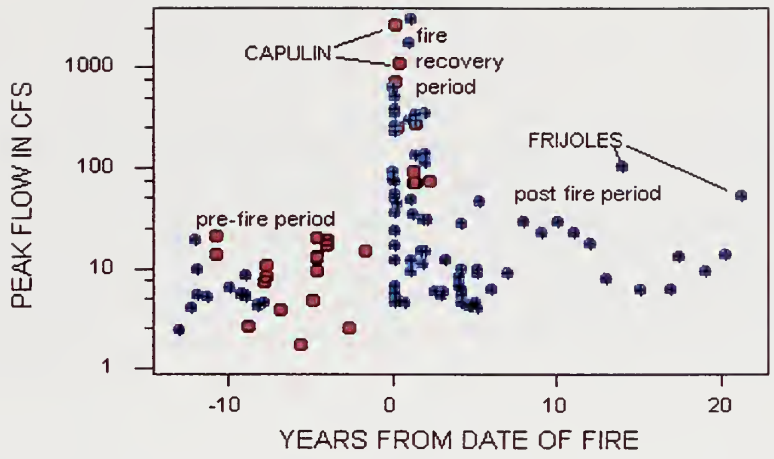

Figure 1. Peak flows in Frijoles and Capulin creeks before and after wildfires.

Frijoles and Capulin Creeks as compared to both pre- and post-burn records, with the number, magnitude, and frequency of peak flows increasing significantly (White and Wells, 1984; Veenhuis, 1998). The largest events on Frijoles were 1,800 and 3,124 cfs (95 and 164 times greater than the pre-burn peak, respectively), and occurred in the same month, July 1978. Peak flow records are available for Capulin Canyon for the years 1985, and 1987 - 1994. While the maximum pre-fire discharge was slightly greater than 21.8 cfs, the estimated peak for the maximum post-fire flow event was 2,700 cfs (Veenhuis, 1998).

Purtymun and Adams (1980) analyzed pre- and post-La Mesa Fire streamflow records and determined "Runoff in 1978 was similar to years 1964-69. Though it appears that the volume of runoff has not changed, the time of collection and retention of precipitation in the drainage area has decreased. This resulted in larger discharge from runoff events." Figure 2 indicates the post-burn hydrograph is flashier, with sharper, higher magnitude flood peaks, and steep limbs. The post-burn hydrograph illustrates a much larger surface component; whereas, the pre-

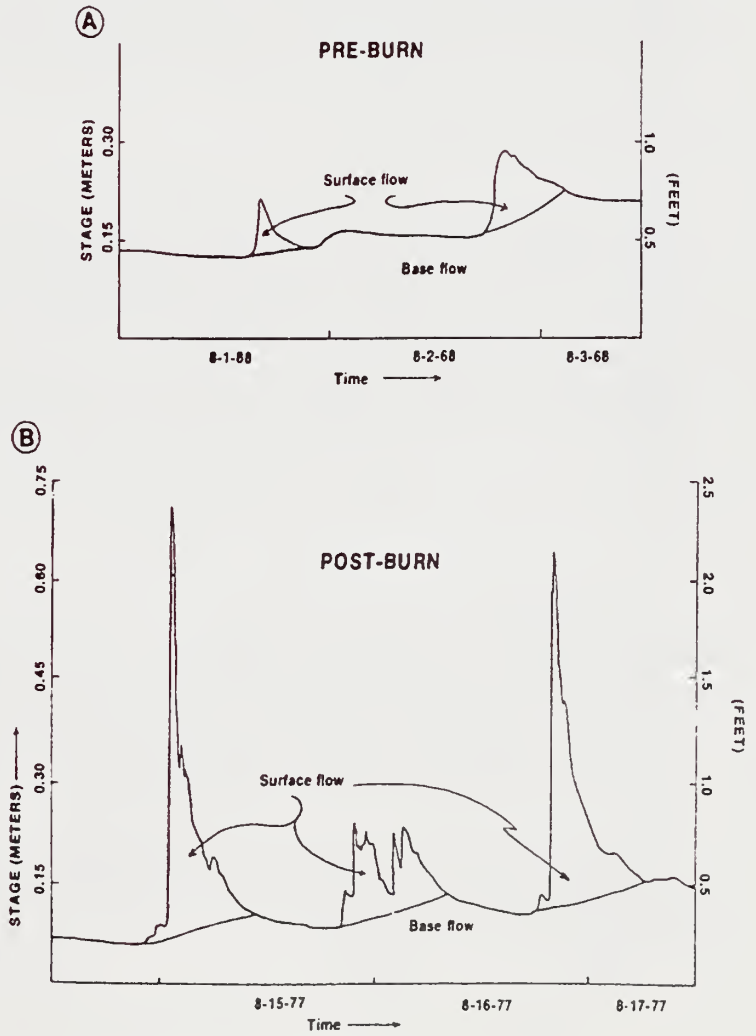

Figure 2. (a) Pre- and (b) post La Mesa Fire hydrographs for Frijoles Creek (White and Wells, 1984).

burn hydrograph has a greater base-flow component. Similar hydrograph relationships were observed on Capulin Creek following the Dome wildfire (National Park Service, 1996).

In both Frijoles and Capulin canyons, a series of damaging flash floods occurred during the three summer monsoon seasons following the fires. Riparian systems sustained direct and indirect impacts associated with alteration of stream channels, banks, and flood plains. Wholesale loss of riparian plants occurred in some cases either by erosion or sedimentation (burial). The pre-fire stream channel was variously downcut many feet to bedrock, significantly widened, and/or the banks undercut. Large rocks and boulders were transported and deposited in clusters, establishing new stream morphologies. In some instances, entirely new channel sections replaced the old ones, either through abandonment or sedimentation (National Park Service, 1996).

Preliminary assessments of the Capulin aquatic system by Stevens (1996) suggest the aquatic invertebrate and water chemistry parameters were significantly altered from pre-fire conditions (National Park Service, 1996). Water chemistry was also affected and both Purtymun and Adams (1980), and MacRury (1997) noted a three- to four-fold increase in the transport of base cations and anions. In Frijoles, a macroinvertebrate reduction of 98 percent was experienced after heavy flooding following the La Mesa fire (Pippin and Pippin, 1980). In addition to the immediate impacts, stream habitat quality was severely impaired and sediment input has increased embeddedness that has been linked to reduced macroinvertebrate density and diversity in Frijoles long after the La Mesa Fire.

Today, even the casual observer can perceive the annihilation of habitat (i.e. pools, riffles, and runs) within Capulin Creek as a result of the floods triggered by the 1996 Dome Fire. The most obvious physical alteration is entrenchment which results in the stream channel being down-cut and widened so that subsequent flood flows are confined to a vertically walled trench and no longer spread out upon adjacent flood plains. The process of regaining a stable channel type is impeded by the inability of naturally low, post-fire bank-full discharges, to redistribute the available bedload and form a stable channel cross-section and new flood plain. Measurement of geomorphic parameters in Frijoles reveals physical habitat alterations still exist in some reaches more than 20 years after the La Mesa Fire (Mott, 1999).

Discussion

Maintenance of natural physical processes is perhaps the most fundamental component of ecosystem management. The community of organisms inhabiting a stream reach has developed over thousands of years, and changes in physical habitat condition and/or distribution will alter these communities, often over large temporal and spatial scales. Fire management is the single most important component of watershed management at Bandelier National Monument. Potential hydrologic responses to fire management activities that must be assessed either directly or indirectly by a monitoring program are reviewed in the following discussion that has been modified from Neary (1995).

Runoff

Fires affect the quantity of water derived from a watershed by reducing interception, storage, transpiration, and infiltration, and increasing overland flow, and surface storm flow. Watershed response to storm events is greater with shortened time to peak-flow and a greater susceptibility to flash floods. Total water yields from burned watersheds are higher, especially in areas where the majority of precipitation is derived from rainfall and the evapotranspiration rate is high. The magnitude of measured water yield increases the first year after the fire disturbance and can vary greatly at one location or between locations depending on the fire intensity, climate, precipitation, geology, soils, watershed aspect, tree species, and proportion of the forest vegetation burned.

Erosion/Sedimentation

Factors favoring erosion following fires are the increased overland and peak flows, fireline construction, temporary roads, and watershed rehabilitation activities. Soil and sediment loss can take the form of sheet, rill, gully, or streambank erosion. Fire associated debris avalanches are a form of mass wasting that delivers sediment directly to streams in large quantities. After fires, turbidity can increase due to the suspension of ash and soil particles. The increased erosion and peak flows can also increase bedloads, which can destroy stream habitat.

Water Chemistry

Wildfires can also interrupt uptake of anions and cations by vegetation and speed up mineral weathering, element mineralization, microbial activity, nitrification, and decomposition. These processes result in the increased concentration of inorganic ions in the soil solution and leaching to streams via subsurface flow. Ammonium-based fire retardants can produce short-term mortality in some aquatic organisms. Non-ionized ammonia is the principal toxic component to aquatic species. Impacts from toxic ammonia levels depend on stream volume, the amount of retardant dropped, and the orientation of the drops to the streams long-axis.

Physical Habitat

Fires can increase stream temperatures by removal of shade and the direct heating of water surfaces. This can result in decreased dissolved oxygen concentrations and increased plant growth. Loss of habitat types and quality, such as caused by in-filling of pools by over-abundant bedload, covering of gravel riffles with fine sediment, bank destabilization, and other changes in fluvial morphology, have been well document at Bandelier. Physical disturbances ultimately cause cumulative impacts on aquatic biota, the longest lasting of which is in-stream habitat degradation.

To date, only the impacts of wildfires on the Monument's water resources have been studied, and the conclusion is that water resource impacts have been both dramatic and long-lasting, affecting watershed function, water quality, stream habitat, and aquatic communities. While it can be assumed that prescribed fires have less impact, there are no data to confirm this assumption or quantify how much impact may occur. Because fire management activities are being

implemented across the majority of the Monument for the foreseeable future, it is critical to answer the following basic questions:

1) What are the within stream responses to prescribed fires? Are changes in runoff, sediment delivery, water chemistry, physical habitat and aquatic communities negligible or quantifiable?
2) If hydrologic responses are quantifiable, how far do they deviate from pre-fire and wildfire conditions?
3) If aquatic resources are being measurably impacted, what changes in prescribed fire activity can be initiated to reduce impacts and what future studies need to be conducted to help guide future prescribed fire activities?

This proposal will yield answers to questions one and two above, and determine whether or not question three needs to be pursued.

Description of Recommended Project or Activity

The purpose of this assessment is to determine the potential impacts of prescribed fire on water resources. With future implementation of fire activities, stream monitoring will be performed to determine the relative impact of prescribed fires on flow, water quality, stream habitat, and biological resources. The most applicable parameters and a description of their utilization relative to this assessment follows:

PARAMETER	DESCRIPTION OF USE
Flow	A sensitive parameter responding dramatically to previous wildfires. Smaller responses to prescribed fire are therefore expected. Peak flows resulting from prescribed fires should be kept below levels that negatively impact habitat or biological communities.
Water Quality	Previous studies have shown changes in base anion and cation concentrations following wildfires. Specific conductance and pH will therefore be monitored to assess statistically significant changes in dissolved ions. Water temperature and dissolved oxygen will also be measured because of their relation to potential increases in sunlight and nutrients. Turbidity will be measured to assess potential increases in suspended solids, and fecal coliform samples will be collected at the gauged monitoring station because this represents a valuable opportunity to assess backcountry water quality as influenced by visitor activities.
Physical Habitat	Before and after measurements of embeddedness, substrate composition, bankfull width, and entrenchment will be performed to determine if potential changes in flow regimes are sufficient to cause stream channel responses. Cross sections will

	be established for before and after surveying. Results should correlate with flow and biological communities.
Biological	**Rapid bioassessment techniques will be employed utilizing macroinvertebrate collections. Results should correlate with flow, physical habitats, and water quality, and determine if changes in any of the above mentioned parameters are causing changes in biological communities.**

Bandelier initiates burn plans for prescribed burning activities several years in advance of the actual burn. Once a key watershed has been proposed for prescribed burning, the USGS can install a pressure transducer and begin development of a rating curve and implement sample collections immediately downstream of the target watershed. For example, Bandelier is currently proposing a large burn in the upper watershed of Frijoles Creek, above the area previously burned by the La Mesa Fire. Funding of the proposed monitoring would allow collection of before and after data on one of the Monument's most important water resources.

Budget

Item and Description	FY2001	FY2002	FY2003
Flow - A stable reach of stream located directly below a watershed proposed for prescribed burning will be instrumented with a pressure transducer and data loger. A stage discharge rating curve will be developed at this gauge and used to convert stage to discharge. Physical hardware must be removed at the end of year three.	13,000	8,000	10,000
Water Quality – Field measurements (conductance, pH, temperature, and dissolved oxygen) and turbidity will be collected once per month or every time discharge measurements are performed. Fecal coliform bacteria will be collected once per month only.	5,000	5,000	5,000
Physical Habitat – Measurements (embeddedness, Wolman pebble counts, bankfull width, depth, and area, entrenchment, and cross-sections) performed once every six months to determine level of natural variability present. Post-fire measurements will be done quarterly if justified by flow data and field observations.	5,000	5,000	7,000
Biological - Standard rapid bioassessment techniques will be used to estimate community structure and diversity within three riffles located near or at reaches where physical measurements will be performed. Biological samples should be collected seasonally before and after the implementation of prescribed fire.	8,000	5,000	5,000
Reporting - A report will be developed at the end of the assessment that summarizes the data and the major findings. The report will focus on significant changes observed as a result of implementation of prescribed fire. Data will be provided to the National Park Service in a digital format to allow further or more detailed analysis if warranted.			10,000
Totals	**$31,000**	**$23,000**	**$37,000**

This proposal requires $91,000 over a 3-year interval from the USGS's Fixed Station Monitoring Program. This approach could be rotated to other areas within the park slated for prescribed burning activities as needed.

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Project Statement
BAND-N-007.007

Last Update: 08/01/99 Priority: 0000
Initial Proposal: 08/01/99 Page Number: 0001

Title: Restore Degraded Stream and Stream Corridor within Bandelier National Monument

Funding Status: Funded: 14.0 Unfunded: 54.0

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number:

Summary

Development and promotion of visitor access in discrete areas of National Parks has the potential to degrade the very resources park managers were mandated to protect. The heavily developed reach of Frijoles Canyon near Bandelier's headquarters is such an area. Unconstrained social usage near Cottonwood Picnic Area has resulted in the trampling of Frijoles Creek's stream banks and channel. Recurrent trampling has produced stream banks devoid of vegetation, an over widened stream channel, decreased sediment size, and increased turbidity and embeddedness. Changes in these stream attributes ultimately result in reduced habitat quality.

The watershed of Frijoles Creek is almost entirely wilderness and backcountry, and natural hydrologic conditions currently prevail upstream of the disturbed reach. This means that flow and sediment transport are also at natural levels, and watershed disturbance is not a contributing factor to disturbance in the reach of stream near the headquarters. The impacts to Frijoles Creek are both local and chronic in nature, and restoration hinges on one principle component, elimination of abusive levels of human traffic. The second recognized need in the disturbed area is revegetation. When exclusion and revegetation measures are implemented, natural processes will allow the stream channel to recover within a few years.

The work to be completed through this project is:

1) Build a fence along both sides of the disturbed stream reach and route traffic from the picnic area to the headquarters facilities across existing bridges;
2) Spread slash over de-vegetated areas to encourage re-growth of native vegetation and further discourage visitor access;
3) Contact visitors crossing into the restoration area and ask them to honor the fence. Monitor reaches above and below the fenced portion of the stream to insure stream disturbance is not transferred to other reaches; and

4) Baseline geomorphic data have already been collected for the disturbed stream reach. Resource management staff and the seasonal employee will use photo-point monitoring techniques to assess stream corridor recovery, and conduct a follow-up geomorphic assessment three years after the fence is constructed.

Problem Statement

Background

Water is often a significant resource in units of the National Park Service, either through support of natural systems, administrative use, or visitor enjoyment. Bandelier National Monument contains a variety of water resources including springs, streams, riparian areas and ground water. Of special significance is Frijoles Creek, the only stream in the Monument, and one of only a few in the middle Rio Grande basin that maintains perennial flow throughout its entire 15-mile length. Frijoles Creek is also central to the interpretive theme of the National Monument. Bandelier was established to preserve what remains of the area's once thriving Ancestral Puebloan culture, and springs, streams, and riparian zones allowed these ancient agrarians to flourish in an otherwise harsh landscape. The occurrence of water over a wide range of elevations and microclimates continues to support Bandelier's diverse assemblage of plants and animals, and provides the visitor from today's world a different manner of sustenance.

The National Park Service maintains a large number of structures and facilities within the canyon, on the flood plain, and across the channel of Frijoles Creek. Within the canyon, these include concessions (restaurant and gift shop) operations, maintenance facility, administrative and support offices, visitor center, access road, and employee housing. Below the elevation of the mapped 100-year flood plain are picnic area restrooms, picnic area and visitor center parking, and sewer lines. Below the mapped 500-year flood plain lie the visitor center and museum, maintenance offices, wood/welding shop, oil house, lumber storage, search and rescue cache, and fire cache. Across the Frijoles channel is one vehicular bridge and several pedestrian bridges. The foundation walls of an older bridge remain on both sides of the stream, and a horse ford crosses the lower headquarters reach. Unlined pit toilets were also in use near Frijoles Creek at Ceremonial Cave just upstream from the headquarters operation, but have been replaced with vault toilets outside of the 100-year flood plain. Most of this infrastructure, with the exception of the pit toilets, is historic Civilian Conservation Corps work.

Infrastructure development within units of the National Park Service is arguably at odds with the Organic Act. To promote intensive visitor access in discrete areas has the potential to degrade the resources the National Park Service was mandated to leave unimpaired for the enjoyment of future generations. Development within the flood plain risks infrastructure damage and visitor and employee safety. Increased storm runoff, sedimentation, hard-structures, and direct trampling of the stream channel can also degrade stream habitat. The generation, transport and disposal of associated sewage have the potential to spill or leak into receiving surface or ground water. Maintenance operations, parking surfaces, and household, office, and yard chemicals are a potential source of hazardous materials that can arrive at receiving streams by both point and nonpoint transfer mechanisms (e.g. DDT and maintenance yard contaminants in Frijoles Creek).

Recreational use of riparian areas throughout the nation is increasing, particularly in the southwest. At the same time, high quality riparian and stream channel habitat along perennial streams in New Mexico is a resource in decline. For example, U.S. Geological Survey physical habitat and geomorphic measurements conducted as part of the NAWQA Program in the Rio

Grande Basin determined that the 300 feet reach of Frijoles Creek below the stream gauge was the only site (out of 10) that had minimal habitat degradation. The habitat at Frijoles Creek was characterized by no stream modification, very little bank erosion, highly stable banks, and dense riparian vegetation (Levings et al., 1998).

Bandelier receives about 420,000 visitors each year. The majority of these visitors utilize the information center, picnic area, and cultural ruins near the headquarters. Of specific concern is the picnic area that is located just upstream from the previously mentioned gauging station. The picnic area is a linear band of pull-offs and picnic tables along about 1,400 feet of the south bank of Frijoles Creek. Running water attracts children, who romp and play in the creek, build small dams, throw rocks, slide down the banks, and grab vegetation to climb back up the bank. On any given day, damage to the stream and streamside vegetation is minimal, but over the course of years, the accumulated impacts have measurably altered this reach of stream.

As part of the field investigation associated with the development of a Water Resources Management Plan for Bandelier (Mott, 1999), a rapid physical assessment was performed near the headquarters. The purpose was to quantify observable alterations to the stream reach at the picnic area, as compared to upstream and downstream reaches. The assessment began with an estimation of the bankfull stage as interpreted from the headquarters gauge and field observations. Parameters measured included bankfull width, flood-prone area, average bankfull depth, substrate size, and embeddedness. Percent vegetative cover was also estimated for both banks. Rosgen's (1996) definition of stream entrenchment was also calculated along with the bankfull area. The study reach began 25 feet upstream from the horse crossing, and measurements were recorded at 50 feet intervals in the upstream direction for a distance of 3,150 feet. The last measured cross-section was 400 feet above the picnic area.

A detailed classification of stream type according to Rosgen (1996) was not possible given the limited amount of geomorphic parameters collected. However, estimation of water surface slope and channel sinuosity reveal that this stream reach is near the cutoff between the B (summarized as fast flowing and constrained) and C (pool/riffle and meandering) stream types. Gravel and lesser amounts of cobble and fines typically dominate the substrate. Limited intervals are dominated by cobble, and other intervals show exposed bedrock (basalt). Figure 1a shows the character and relationship of bankfull width, substrate size and vegetative cover throughout the surveyed reach. Figure 1b shows the same data using a five-point moving average that allows the general trends to be more easily interpreted.

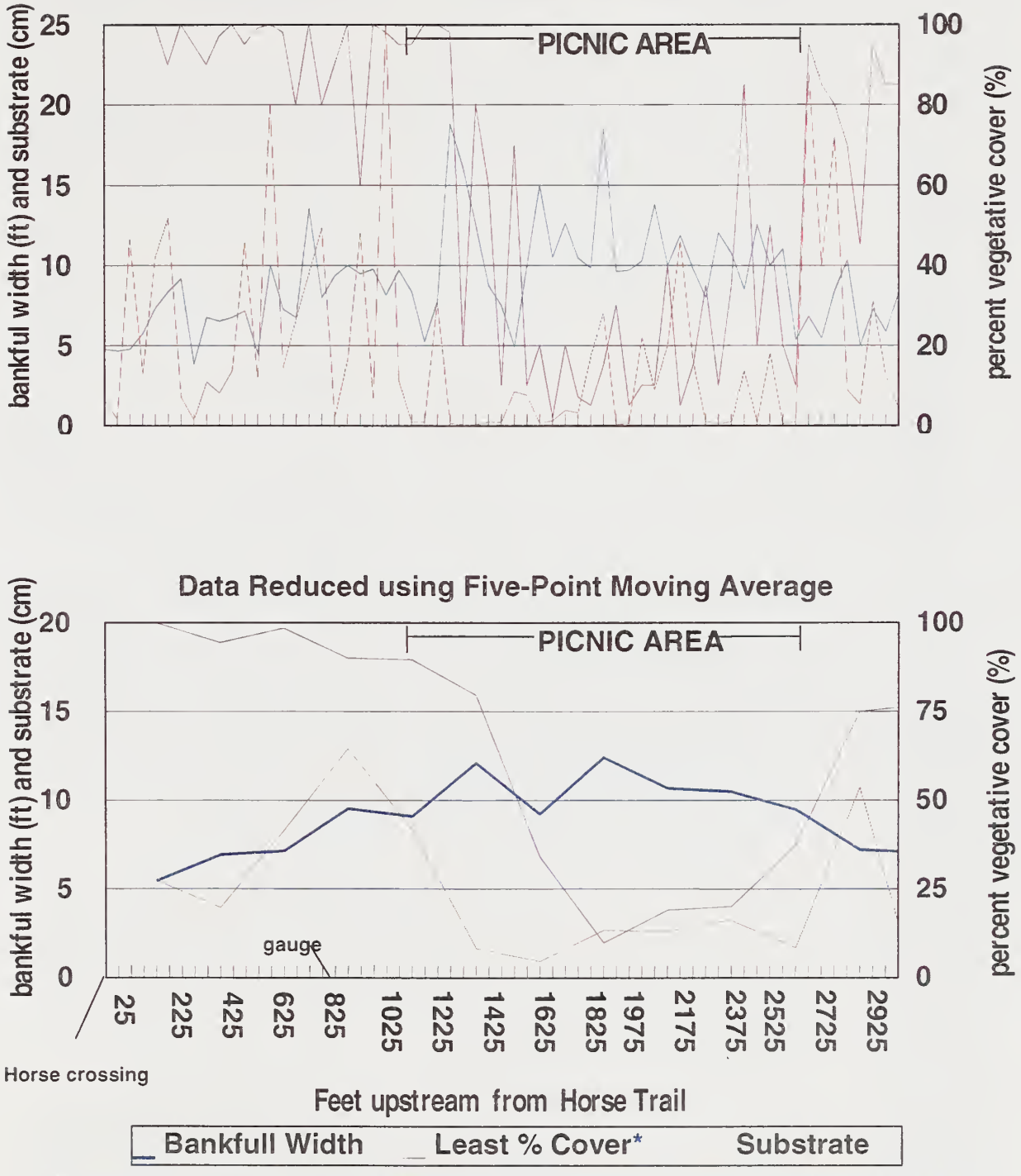
These data show that direct trampling of stream banks has caused a reduction of vegetative cover from near 100 percent above and below the affected reach to an average of 20 to 30 percent within the affected reach (many intervals of completely bare banks were observed). Average bankfull width is 75 percent (from 7.25 to 10.6 feet) to 83 percent (from 6.5 to 10.6 feet) greater than upstream and downstream reaches, respectively. Maximum bankfull widths observed above and below the degraded reach were 10.3 and 10.0 feet, while along the picnic area the maximum bankfull width was 18.8 feet. Narrow stream reaches, due to their inherent higher velocities, are more efficient at transporting bed (particles bounced along on the stream bottom) and suspended loads.

Also shown in Figures 1a and b is the average sediment size below the bankfull stage. Within the reach showing reduced vegetative cover and increased bankfull width, the average substrate size decreases, and fine particles (mud and sand) become increasingly dominant. In correlation with the decreased substrate size was a tendency toward increasing embeddedness. In many

intervals within the degraded reach, fines completely covered the substrate, which was never observed above or below. Increased abundance of fines decreases habitat diversity. Reduced habitat values can take many forms, including filling of pools, reduction of pool volume, increased shallow runs, loss of cobble and gravel substrate which provides cover from predators, spawning areas, and protection from flooding, and shifting substrate which increases turbidity and decreases periphyton (attached aquatic plant) production. Because habitat value is diminished, aquatic communities typically show reduced biological diversity and a shift toward more tolerant species in geomorphically degraded reaches.

A final observation from the rapid physical assessment data is the significant increase in the number of cross-sections categorized as entrenched in the vicinity of the picnic area. An entrenched stream reach no longer has access to its flood plain, and is often indicative of past or ongoing degradation, either at the local or watershed scale (Rosgen, 1996). In this case, the upstream and downstream reaches are not entrenched, which indicates degradation on a local scale. It should be noted that cross-sections measured by Veenhuis (1998) on Capulin Creek show this stream to be entrenched as a result of post-fire flooding and associated channel degradation. Physical descriptions of the Frijoles channel following the La Mesa fire indicate a similar degraded and entrenched stream state throughout many reaches (White and Wells, 1984; White, 1996).

Natural sediment transport and deposition processes will allow entrenched streams to redevelop flood plains within the over widened and often down cut channels. This flood plain rebuilding process appears to have been effective above and below the picnic area over the 20 years since the La Mesa fire. However, the reach near the picnic grounds remains mostly entrenched. From this it can be inferred that the stream reach adjacent to the picnic area never recovered from the post-fire flooding, and that the lack of recovery is a result of recurrent trampling and loss of stabilizing vegetation.



*** Bank (left or right) with least percent vegetative cover used as plot value**

Figure 1. Top (a) Rapid Physical Assessment Results for Headquarters Reach on Frijoles Creek; Bottom (b) Five Point Moving Average.

Description of Recommended Project or Activity

Restoration of the headquarters reach of Frijoles Creek will require controlling visitor impacts to the stream and streamside vegetation. As stated in the recently completed Water Resources Management Plan (WRMP), Frijoles Creek near the headquarters is the most chronically impacted reach of stream in the Monument, and probably contains the most degraded aquatic habitat and communities. It was also noted that the National Park Service has complete control over this area, and observed impacts, along with restoration, are solely NPS responsibility.

The stream channel and riparian restoration activities to be implemented through this project include:

1.) **Fence Construction -** A freestanding pole fence will be constructed along both sides of Frijoles Creek for a length of 1,800 feet (3,600 feet of fence total). This fence will be made of local material and be designed to blend in with the historic fabric of the area to the maximum extent possible. The fence will be made of zigzagged poles so that it will stand without need for supporting posts and concomitant ground disturbance, a serious consideration in this nationally significant archeological area and National Historic District. The fence will be integrated with a number of pedestrian bridges already in place throughout the disturbed reach that will allow the free movement of visitors between the picnic area and the visitor center, concessions operations, and other facilities. Information signs will be placed on the fence asking visitors to refrain from entering the restoration area.

2.) **Slash Spreading** - When the poles are made for the fence, a significant amount of slash in the form of branches will be generated. Much of this slash will be used to provide a more favorable growing medium for native vegetation on the stream banks and within the riparian zone of the restoration area. Previous restoration work by the Vegetation Specialist at Bandelier has shown dramatic response to slash application because slash provides stability to eroded stream banks, provides micro-sits for establishment of riparian vegetation, and deters visitor traffic. As an added benefit, the slash will discourage visitors from entering the restoration area because they will not wish to climb over the downed brush.

3) **Monitor visitor compliance**- A seasonal employee will be hired during the period of highest visitation to contact visitors who cross into the restoration area and ask them to honor the fence. Seasonal employee will also monitor reaches above and below the fenced portion of the stream to insure stream disturbance is not transferred to other reaches. Modification and expansion of the visitor exclusion strategy will be initiated if warranted. The parking lot attendants will also participate as time permits.

4.) **Monitoring** - Resource management staff and the seasonal employees will use photo-point-monitoring techniques to assess stream corridor recovery. Baseline geomorphic data have already been collected for the disturbed stream reach, and a follow-up geomorphic assessment will be conducted 3 years after the fence is constructed to determine the rate and extent of channel and vegetative recovery.

Budget	$$FY01$$		$$FY02$$		$$FY03$$	
Item and Description	NPS	BAND	NPS	BAND	NPS	BAND
Fence Construction – Through hiring of two seasonal employees (GS-5), BAND will oversee construction of exclusion fence. It is estimated that 3,200 poles approximately 15 feet in length will be required to construct a freestanding fence 4 feet tall and 3,600 feet long. Estimated cost for cutting, delivery, and construction is $5 per pole, plus incidental costs. BAND will develop and administer contract and complete all aspects of compliance. Compliance requirements are anticipated to require a substantial amount of effort on the part of BAND's resource management staff.	21,000	6,500	17,000	6500		
Slash Spreading – The seasonal employees will also be required to bring in slash generated during pole cutting and spread over denuded stream banks and riparian areas within the confines of the fenced area. BAND staff will be responsible for oversight of the seasonal employees.						
Monitor Visitor Compliance- An additional duty of the two seasonal employees will be to patrol the exclusion zone, informing visitors about the restoration program, asking for their voluntary compliance, and repairing vandalism. These seasonal employees will also conduct photo-point-monitoring of the restoration area at the beginning and ending of each season. Employee will pay particular attention to visitor use activity above and below the exclusion area to insure impacts are not transferred to other stream reaches. In the final season (year 3), one seasonal employee, with assistance and oversight from Bandelier staff, will conduct follow-up geomorphic assessment of the recovering stream reach, as was performed during the original assessment discussed previously in this proposal. BAND will provide supervision and overhead support.					2000	1000
Totals.....	**$21,000**	**$ 6500**	**$17,000**	**$6,500**	**$2,000**	**$1,000**

Acronyms:
BAND = Bandelier National Monument
NPS = National Park Service, Disturbed Lands Restoration Projects (Small) or, Hydrology, Watershed Management, and Planning - both NPS funding categories have a 2 year duration, waiver will be required to meet the 3-year time frame required

With this proposal, Bandelier National Monument is requesting $54,000 from the [**Fill in Funding**] program over a 3-year interval as detailed and distributed in the preceding budget. Bandelier will provide $14,000 (26%) of the required expenditures for this restoration project.

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Project Statement
BAND-N-007.008

Last Update: 08/01/99 Priority: 0000
Initial Proposal: 08/01/99 Page Number: 0001

Title: Assess Potential Sewage Leakage at Bandelier National Monument

Funding Status: Funded: 23.0 Unfunded: 45.0

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number:

Summary

High fecal coliform counts are often observed in Frijoles Creek at and below the Monument's headquarters relative to upstream sites and periods of lower visitation (Bracker, 1995). The Monument staff is concerned that subsurface leakage (exfiltration) from the aging sewage collection and/or pumping system is contaminating nearby Frijoles Creek. This concern is based mainly on the fecal coliform monitoring results and the discovery of *bis* (2-ethylhexyl) phthalate in Frijoles Creek at levels similar to those observed below a nearby sewage treatment plant (Purtymun et al., 1988). However, there has been no conclusive link between the sewage exfiltration and water quality impairment.

As part of the development of a Water Resources Management Plan for Bandelier, a hydrologist with the Water Resources Division (WASO) examined the infrastructure layout within Frijoles Canyon and past water quality monitoring results. While the weight of evidence appears to implicate exfiltration as the cause of previously noted water quality impairment, other possible explanations were also provided. Before expensive and invasive rehabilitation work can be justified, it was recommended that a study designed specifically to assess potential exfiltration should be implemented.

Specific activities recommended in this project include: 1) DNA analysis of fecal coliform bacteria within Frijoles Creek, 2) installation of three shallow ground water monitoring wells, 3) screening of surface and ground water for optical brighteners and caffeine, and 4) dye tracing. A qualified consultant operating under the direction of both Monument staff and a Water Resource Division hydrologist will perform this work.

PROBLEM STATEMENT

Bandelier National Monument is one of the oldest units of the National Park Service. It was established in 1916 to preserve what remains of the area's once thriving Ancestral Puebloan culture. Early infrastructure development within the Monument occurred near the most impressive archeological sites, which also happened to be in the bottom of Frijoles Canyon and adjacent to the Monument's most significant water resource, Frijoles Creek. Through the years, and especially during the Civilian Conservation Corps (CCC) era of the 1930s, this infrastructure grew to include a maintenance compound, employee housing, a visitor center and museum, parking lots, office space, and concessions operations, among others.

Today we recognize that infrastructure development within units of the National Park Service is arguably at odds with the Organic Act. To promote intensive visitor access in discrete areas has the potential to degrade the resources the National Park Service was mandated to leave unimpaired for the enjoyment of future generations. For example, a fishing ban is still in effect on Frijoles Creek as a result of DDT contamination from Bandelier's maintenance compound in the 1950s and 60s. Another concern, and the focus of this proposed study, is potential leakage (exfiltration) from Bandelier's aging sewage collection system into the shallow ground that feeds Frijoles Creek.

Sewage infrastructure serving the headquarters complex also dates to the CCC era and once utilized spray fields in lower Frijoles Canyon as a disposal mechanism (National Park Service and U.S. Department of Energy, 1993). In 1973, a lift station was installed and sewage was then pumped over 500 feet in elevation to the mesa north of the headquarters into a series of lined lagoons. Greater visitation necessitated a 1993 project that enlarged the lagoon capacity. Problems and potential problems associated with the existing sewage system include leakage from the aging collection network and overflows near the lift station.

Jacobs (1996) reported blockage of the Bandelier sewer system in the main parking area at the gravity collection junction and manhole cover that resulted in the spillage of raw sewage into Frijoles Creek. He also stated that this was the second spillage he was aware of in 3 years. Maintenance staff believe conversion to low-flow toilets increased the solids to water ratio overwhelming the design capacity of the gravity collection network (i.e. gradient too low) under certain conditions.

Park-based water quality sampling has been conducted in the past to assess potential external impacts and determine if backcountry recreation or headquarters development (sewage system, horse corral, picnic area, pit toilets, maintenance compound, etc.) were impacting water quality. One of the most sensitive parameters related to these goals is fecal coliform bacteria. Fecal coliform measurements were made every two weeks from six stations along the developed portion of Frijoles Creek during 1976 to 1978, 1982 to 1985, and 1993 to 1994 (National Park Service, 1995a).

Bracker (1995) interpreted the results of bacteria samples collected from Frijoles Creek on 27 recording dates between December 7, 1993 and December 5, 1994. Samples were collected at eight stations; the most upstream was at the Wilderness Boundary above Ceremonial Cave, and

the most downstream was below the infrastructure, including the horse corral. These samples were tested for fecal coliform and fecal streptococcus bacteria. Sampling in the headquarters reach occasionally found fecal coliform levels in excess of 3,000 colonies per 100 milliliters (col/100mL), apparently documenting intermittent sewage system failures. State standards require bacteria levels to remain below 200 col/100 mL (New Mexico Water Quality Control Commission, 1995). Bracker concluded:

- Bacterial contamination of the stream rises markedly during the warm summer months when visitation is highest. Unfortunately, turbidity was not measured. When turbidity and fecal coliform bacteria exhibit positive correlations, it provides evidence that adsorbed bacteria are either being resuspended with stream sediments (i.e. from visitors wading in the stream above the sampling station) or washed in from nonpoint sources. When a correlation between turbidity and bacteria is weak, it indicates the bacteria are in solution and probably result from point sources or ground water;

- There is an erratic tendency for Frijoles Creek to become more contaminated as it flows through the heavily used part of the canyon. In some cases there is a marked increase in bacteria counts at a specific point. This may indicate that discrete events (spills at the lift station, spillovers at the horse corral due to heavy rain...) are being observed. In other cases, there is a slow steady degradation in water quality throughout this portion of the stream;

- A characteristic pattern seems to be low readings at stations one to four (above the visitor center) and high at stations five to eight (below the visitor center). This pattern is most evident when the overall contamination is fairly low. On one occasion, there was a fairly abrupt rise between stations four and five;

- After two days of rain, bacteria counts are consistently high, and spike very high at the horse corral (stations 7 to 8). Runoff of manure-laden water into the creek was suspected. The yearly highs seem to fall in July when summer rains typically begin. After August, the trend is dramatically downward (as is visitation);

Bandelier developed a strategy to mitigate contamination from the Frijoles horse corral and implemented it in 1995 (Jacobs, pers. comm., Bandelier National Monumnet, 1998). Mitigation included routing surface runoff from the drainage area above the horse corral around the corral, frequent clean-up and removal of waste, and boarding the horses outside the canyon when they are not needed for backcountry patrols. A follow-up study by Stevens (1996) investigated water quality above and below horse corrals on Frijoles and Capulin Creeks using benthic macroinvertebrates, fecal coliform, physical characteristics, and several water chemistry parameters. Stevens found no significant differences in water chemistry or fecal coliform upstream and downstream of either horse corral following implementation of corrective measures. However, there was an inverse relationship between fecal coliform counts and flow in Frijoles Creek, which indicates bacteria are being supplied from a point source (such as a continuously leaking sewage pipe). This inverse relationship was not observed in Capulin Creek that is in a wilderness setting.

Purtymun et al. (1988) detected the compound *bis* (2-ethylhexyl) phthalate in Frijoles Creek at a level of 560 ug/L. Phthalates are common in surface waters receiving sanitary effluent and the Frijoles concentration is equivalent to levels measured below a sewage treatment plant in Los Alamos County (National Park Service, 1995a). As part of the development of a Water Resources Management Plan for Bandelier, a hydrologist with the Water Resources Division examined the physical setting within Frijoles Canyon and past water quality monitoring results discussed briefly above. While the weight of evidence appears to implicate exfiltration as the cause of previously noted water quality impairment, other potential explanations/sources include:

1. High phthalate concentrations could have resulted from a direct spill at the lift station;
2. Leachate from unlined pit toilets at Ceremonial Cave could produce elevated fecal coliform during the busy season (these pit toilets were replaced with vault toilets prior to implementing this study). The old pits are scheduled for *in situ* burial in the near future;
3. Natural sources, such as the turkey vulture roost in the Frijoles riparian area, could add fecal coliforms to the stream on a seasonal basis; and
4. Storm flows could wash naturally occurring bacteria, and backcountry human and horse waste, into the stream. Recent work by Steele (pers. comm., Fayetteville, AR, 1998) shows bacteria can remain viable in stream sediments for a time far in excess of reported half-lives. Visitors wading in Frijoles Creek near the picnic area can stir up these sediments, resuspending bacteria in the water column.

Before expensive and invasive rehabilitation work can be justified, the Water Resources Management Plan recommended that a study designed specifically to assess potential exfiltration should be implemented.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY

Past water quality data and the general condition of the headquarters sewage infrastructure points to the need for further addressing possible sewage contamination. The most obvious need pointed out in the Water Resources Management Plan is replacement or retrofitting the gravity feed network to alleviate problems that result in sewage overflow to Frijoles Creek. Less obvious, and the subject of this proposal, is the potential for chronic leakage to ground water, and subsequently Frijoles Creek, from cracks in the aged subsurface sewage lines. Investigations to be conducted through the funding of this proposal include:

1. **DNA Analysis of Fecal Coliform Bacteria** - Recent developments in DNA matching allow the determination of the source animal or animals responsible for contributing fecal coliform bacteria to natural waters. Unique DNA "fingerprints" are matched against a library of known DNA structures from the fecal material of various animals (including humans). The results definitively reveal the host organism responsible for the bacteria present on the body of water being studied. In this case, bacteria samples will be collected from 3 sites on Frijoles Creek just before, during, and after periods of highest visitor use. Sampling stations will be located above, adjacent to, and below, the zone of infrastructure development. Samples would be collected and incubated using standard enumeration procedures, and then plates with positive colonies would be sent to a qualified laboratory for DNA matching. If a

significant portion of the bacteria were indeed from human sources, this would further substantiate exfiltration as the source of the previously observed high bacteria counts;

2. **Installation of Shallow Ground Water Monitoring Wells** - Frijoles Canyon contains a large volume of alluvial and colluvial material (unconsolidated deposits from streams and canyon wall breakdown, respectively). Because Frijoles Creek maintains perennial flow throughout its length, it can be predicted that these unconsolidated materials contain shallow ground water. What is not as certain is the direction of ground water flow within these deposits. Is Frijoles Creek a gaining stream adjacent to the headquarters such that ground water is flowing toward the stream? Or is Frijoles Creek a losing stream such that ground water is moving out of the stream. Or is Frijoles Creek gaining during some seasons and losing during others? These are important questions relative to the exfiltration issue. If water level monitoring shows the water table falls with increasing distance from the stream (losing reach), then contaminants leaking from the sewage system would be transported away from the stream. If the water table dips toward the creek (gaining reach), exfiltrated sewage would be carried toward Frijoles. Three shallow ground water monitoring wells will be installed within the unconsolidated canyon bottom deposits. These wells should be relatively easy to install through the use of highly portable auguring devices and be less than 40 feet deep. Once the wells are surveyed relative to each other, water elevation monitoring will allow determination of flow direction. Measuring the response of the water level to changing flow conditions will also allow an understanding of the hydraulic conductivity within the alluvial deposits. Finally, the monitoring wells will be used in later phases of the study as detailed below;
3. **Screen Surface and Ground Water for Optical Brighteners and Caffeine** - Screening for sewage/human specific contaminants would be conducted in the second year of the study after the monitoring wells are in place and some information has been collected regarding ground water flow and water table fluctuations. Caffeine is a good screening chemical because it is not found in natural waters, yet is extremely common in sewage effluent because caffeine is consumed by a large sector of the public and readily excreted from the body. Another compound which can be utilized in sewage effluent screening studies is optical brighteners used in laundry detergents to get clothes "whiter than white". Their presence in alluvial ground water or Frijoles Creek would also implicate sewage exfiltration. Water samples will be collected from Frijoles Creek and the ground water monitoring wells and analyzed directly for the presence of caffeine. Cotton balls will be placed in Frijoles Creek below the zone of infrastructure and within the ground water monitoring wells. The cotton will absorb optical brighteners, and subsequent examination of the cotton balls under ultraviolet light reveals the presence of the fluorescent optical brighteners; and
4. **Dye Tracing** - A qualified ground water hydrologist will be retained to inject tracer dyes into the Monument's sewer system. Sampling for the dye would be conducted in both the monitoring wells and Frijoles Creek. Positive detection of the tracer dyes from either location would indisputably confirm exfiltration from the Monument's sewage collection lines.

The combination of studies recommended above represents the necessary level of data acquisition required to fully resolve the long-standing uncertainties associated with Bandelier's sewage infrastructure and documented contamination in Frijoles Creek. The combined results

will provide the weight of evidence needed to either conclusively rule out exfiltration, or justify remedial expenditures. The ground water work will also yield flow direction information pertinent to contaminant issues associated with Los Alamos National Laboratory, and should be coordinated with LANL and the New Mexico Department of Environmental Quality's LANL Oversight Bureau.

BUDGET

ITEM	$$$ FY01 $$$ NPS	BAND	WRD	$$$ FY02 $$$ NPS	BAND	WRD
DNA Analysis - Contractor will collect water samples, incubate bacteria, and forward petri plates with positive results to qualified DNA analysis laboratory. BAND will provide contracting expertise and administer contract. WRD hydrologist will assist with technical details.	5	2	3			
Install Monitoring Wells - Contractor will perform well installation, surveying, and water level monitoring as directed by Water Resource Division hydrologist coordinating project. BAND staff will provide necessary compliance work and documentation.	20	5	5			
Marker Screening - Contractor will perform sample collection and conduct analysis or arrange to have samples analyzed by qualified laboratory. BAND will coordinate sampling and contract administration.				5	2	
Dye Tracing - A qualified geohydrologist will use the monitoring wells and previously collected data to develop a dye tracing study designed to detect exfiltration. BAND will assist with implementation and a WRD hydrologist will assist with technical requirements.				10	2	2
Final Report - Contractor will be required to assemble all data and results and develop a comprehensive final document with conclusions. WRD will provide review and comments regarding the report.				5		2
TOTALS.....	25	7	8	20	4	4

BAND = Bandelier National Monument
WRD = Water Resources Division
NPS = National Park Service, Water Quality Mitigation and Restoration Program

With this proposal Bandelier National Monument is requesting $25,000 if FY01 and $20,000 in FY02 from the National Park Service's Water Quality Mitigation and Restoration Program. National Park Service contributions will be matched by $11,000 from Bandelier National Monument for contracting, compliance, and implementation work, and by the Water Resources Division who will provide technical guidance through a parallel technical assistance request. Time and travel for the Water Resource Division hydrologist is estimated to require $12,000 from this source. Total project cost is estimated at $68,000, of which $23,000 (34%) will be contributed by the park or Water Resource Division technical assistance.

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Project Statement
BAND-N-007.009

Last Update: 08/01/99 Priority: 0000
Initial Proposal: 08/01/99 Page Number: 0001

Title: Assess Flooding Potential above Developed Areas at Bandelier National Monument

Funding Status: Funded: 0.00 Unfunded: 0.00
Technical Assistance Request

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number:

Summary

Some of the infrastructure at Bandelier National Monument's headquarters is within Frijoles Canyon's mapped 100-year flood plain, and portions have been flooded in the past. In the nearby Capulin Canyon, a wilderness cabin is located in the 100-year flood plain and is required occupancy for wilderness patrol rangers. In historic times, large magnitude floods have only been documented during post-fire periods. Overbank flooding has also been observed due to logjams. Geomorphic indicators suggest that potentially devastating floods have occurred in the geologic past.

Recent post-fire flooding in Capulin Canyon caused incision of the stream channel by as much as 8 feet over miles of stream length. Some of this incision took place at the toe of colluvial slopes formed at the base of the steep canyon walls. Landslides within the canyon system of Frijoles Creek have been documented in the past. Allen (1999) mentioned that "the point in the narrows of mid-Frijoles where the rockfall exists is a place where in the past a substantial impoundment apparently occurred, which likely caused a major flood downstream when it finally breached." A scenario of concern is that colluvial slopes destabilized by incision might landslide across Capulin's or Frijoles' channel, temporarily damming stream flow. When the slide material is subsequently over-topped, rapid incision and failure of the "natural dam" could result in an outbreak flood, or the rapid release of the water temporarily stored behind the dam.

The second concern to be addressed by this technical assistance is the potential for overbank flooding above developed areas. Overbank flooding occurs when the natural channel of a stream is blocked and high flow events are routed out of the natural channel and onto the flood plain. In the case of Bandelier, logjams often form in stream channels and can sometimes impede the channel's ability to pass high flows. Bandelier staff has removed such debris jams in the past.

The basic questions that need to be answered are:

1. What is the potential for landslides within Bandelier's canyon systems, especially on Capulin Canyon where recent down cutting has occurred?
2. If a landslide did occur, what would be the "worst case scenario". Is the colluvial material of such a size and composition that it could be rapidly breached and release an outbreak flood?
3. Is overbank flooding a threat to Monument property or lives?
4. Are there overbank flow paths on floodplains that might route high water directly at the infrastructure?
5. At what level should natural logjams be considered a threat to Monument infrastructure and removed?
6. How should log jams be removed to minimize deviation from natural processes and minimize destruction of instream habitat?

This request proposes that specialist's from the USGS and the NPS cooperatively develop the response to the above questions. The USGS geomorphologist will have primary responsibility for data gathering, interpretation, and analysis under their technical assistance to parks program. The NPS hydrologist will be the primary liaison with Bandelier's staff and management and develop final conclusions and recommendations.

Problem Statement

Background

The National Park Service maintains a large number of structures and facilities within the canyon, on the flood plain, and across the channel of Frijoles Creek. Within the canyon, these include concessions (restaurant and gift shop) operations, maintenance facility, administrative and support offices, visitor center, access road, and employee housing. Below the elevation of the mapped 100-year flood plain are picnic area restrooms, picnic area and visitor center parking, and sewer lines. Below the mapped 500-year flood plain lie the visitor center and museum, maintenance offices, wood/welding shop, oil house, lumber storage, search and rescue cache, and fire cache. Across the Frijoles channel is one vehicular bridge and several pedestrian bridges.

Flood plain Management Guidelines issued by the National Park Service (1993) require NPS units to avoid direct and indirect flood plain development wherever there is a practical alternative. At Bandelier, development of the Frijoles Creek flood plain includes pre-historic, historic, and modern structures. This infrastructure predates the 1977 Executive Order (11988) that originally required federal agencies to avoid occupancy and modification of flood plains. The Executive Order and NPS management guidelines also

require reducing the risk of flood loss through the implementation of flood plain planning and restoration of natural and beneficial values of flood plains. When the regulatory floodplain must be used, mitigation needs to be employed to protect up to the regulatory flood plain level.

In compliance with Executive Order 11988, a flood hazard survey was completed for Frijoles Canyon in 1987 (National Park Service, 1995). Flood frequency data derived from U.S. Army Corps of Engineers (COE) regionalized graphs, along with cross-sections developed by NPS staff, were used to estimate 10-year, 50-year, 100-year, and 500-year flood plain elevations for Frijoles Creek near Monument headquarters. Water surface elevations were predicted using the COE's HEC-2 computer program. Maps and tables were produced showing the area inundated and maximum depth of flow for each event (U.S. Army Corps of Engineers, 1987).

The 100-year and 500-year flood plains were delineated on a 1935 topographic map constructed by the National Park Service with a contour interval of 10 feet. Review of these maps by Jacobs (1998, pers. comm.) indicated only the picnic area and its restrooms, along with the wilderness parking lot, would be inundated by a 100-year flood. A 500-year flood would reach the visitor center (restroom wing), maintenance facility (wood/welding shop, oil house, and lumber storage), and the search and rescue and fire cache. Maximum flood depths in the vicinity of the headquarters infrastructure area would be 12.2 feet with a maximum width of 320 feet for the 100-year flood, and 13.6 feet and a maximum width of 364 feet for the 500-year flood.

The farthest downstream cross-section that was modeled was completed near the same location as the USGS gauging station. The largest flood of record at this gauge (3,030 cfs) attained a maximum stage height of 6.34 feet (between 5.0 and 5.5 feet above channel thalweg). The 100-year and 500-year flows from the COE study were 2,750 cfs and 6,500 cfs, respectively. It is apparent that the routing equations used by the COE were in error, and that they failed to cross check their predicted stage/discharge relationships with actual USGS measurements. Predicted stage height (12.2 feet) for the modeled 100-year flood (2,750 cfs) is over twice the actual stage height observed during a 3,030 cfs event.

McLin (1992) used HEC-1 and the predicted 100-year, 6-hour design storm for the Los Alamos area to generate hydrographs for Frijoles and other watersheds in and near LANL. Predicted HEC-1 peaks along with stream channel geometry and basin characteristics were used to compute the 100-year flood plain elevations. Similar techniques were used to model other recurrence interval storms and flows, and comparisons were made to USGS flood-flow frequency equations but not actual discharge records. McLin appears to justify the accuracy of his results based on his and other's personal observation of stream response to actual storms. It is interesting to note that peak discharge for a two-year recurrence event in a 20 mi^2 watershed is about 15 cfs, which is very similar to pre- and post-fire maximum observed flows from Frijoles and Capulin Canyons. McLin made no effort to include the relationship between fire and runoff as a potential complicating factor in the model.

Taken from McLin's work is a graph of various return interval flows for Frijoles Creek at the USGS gauging station (Figure 1). Note that the 100-year flood has a peak calculated discharge of 853 cfs, significantly less than both the COE predicted 100-year flow of 2,750 cfs and the maximum post-fire observed flow of 3,030 cfs. Using McLin's graph and employing the equation for the best-fit line, a flood of 3,030 cfs would have a predicted recurrence interval in excess of 4 million-years. This is of note because McLin states "an observed 100-yr 6-h storm has never been recorded at Los Alamos," yet according to his calculations, a 4-million year flow event has been observed.

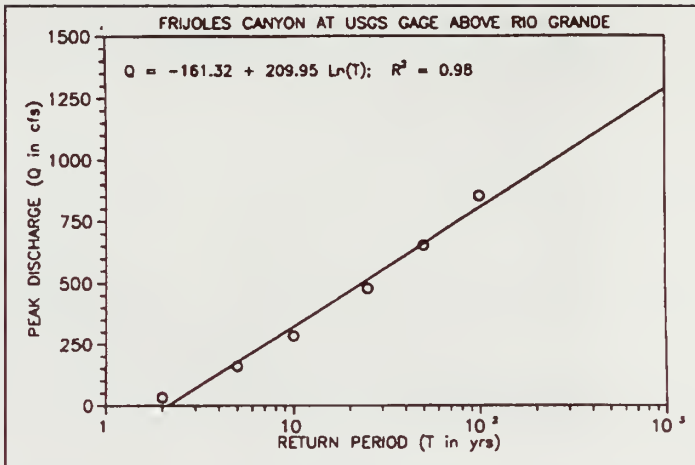

Figure 1. Peak Discharge as a Function of Return Period for Frijoles Creek (McLin, 1992).

It is hoped that the above and previous discussions lead the reader to agree that reliance on hydrologic modeling that employs regional curves or generalized parameters can be misleading. The watershed responses to precipitation on the Pajarito Plateau are unusual if not unique, and are treated in more detail in Bandelier's recently completed Water Resources Management Plan (WRMP). Based on analysis reported in the WRMP, it was concluded that general field observations are probably more important than detailed mathematical modeling and include:

1. The magnitude of historic flooding has less to do with the size of precipitation events than the condition of the watershed;
2. Geomorphic and tree scar evidence indicates floods even larger than observed post-fire floods have occurred in Monument streams. The cause of these floods is unknown, but a 9,000 to 10,500 cfs flood as determined for past floods on Capulin Creek would cause major damage to the headquarters infrastructure;
3. Outbreak flooding from washout of localized landslides appears to be a possible mechanism for explaining large floods;
4. Overbank flows resulting from debris jams (especially where the channel is restricted by bridges) has the potential to flood headquarters facilities even during relatively minor flows, making concern over specific return interval floods inconsequential;
5. Even the large post-fire floods did relatively little infrastructure damage, only causing minor flooding of the visitor center; and,
6. The possibility of flooding the headquarters complex appears to be greatly reduced by management of the watershed in keeping with historic fire regimes and vegetative assemblages.

Fluvial Geomorphology

The following discussion focuses on the physical condition of Bandelier's streams. Maintenance of natural physical processes is perhaps the most fundamental component of ecosystem management. The community of organisms inhabiting a stream reach has developed over thousands of years, and changes in physical habitat condition and/or distribution will alter these communities, often over large temporal and spatial scales.

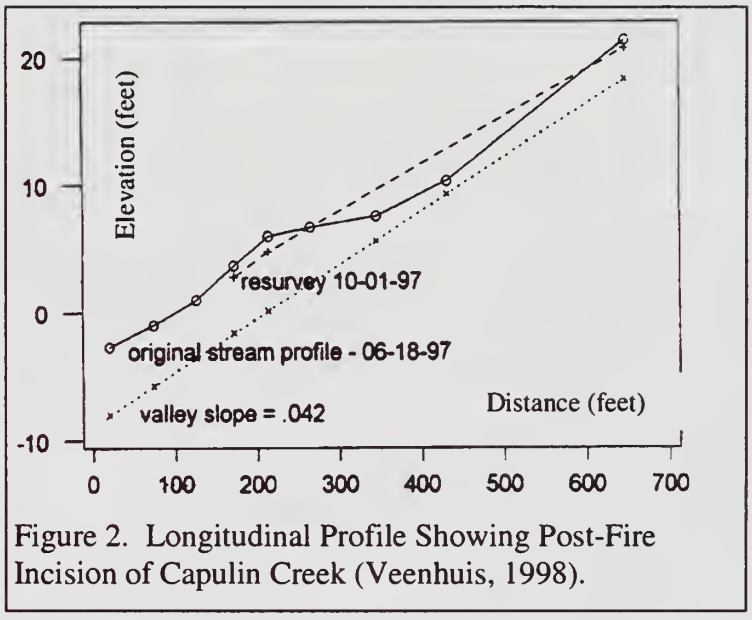

Figure 2. Longitudinal Profile Showing Post-Fire Incision of Capulin Creek (Veenhuis, 1998).

Even a casual observer can perceive the annihilation of habitat (i.e. pools, riffles, and runs) within Capulin Creek as a result of the floods triggered by the 1996 Dome Fire. The most obvious physical alteration is entrenchment which results in the stream channel being down-cut and widened so that subsequent flood flows are confined to a vertically walled trench and no longer spread out upon adjacent flood plains. The process of regaining a stable channel type is impeded by the inability of post-fire bank-full discharges to redistribute the available bedload and form a stable channel cross-section and new flood plain. Close scrutiny of geomorphic parameters in Frijoles reveals physical habitat alterations still exist in some of its reaches more than 20 years after the 1977 La Mesa Fire.

Figure 2 shows the response of a portion of the Capulin channel to Dome Fire induced flooding. Incision in the reach adjacent to Capulin Base Camp was as great as 4.7 feet. Maximum incision observed by the author further upstream was estimated to exceed 8 feet (Photo 1 and 2). In other reaches, cobbles and boulders excavated by the floods were re-deposited, burying the pre-existing channel. A striking example of channel response to post-fire flows is shown in Figure 3 and Photo 3. The gauge and flume labeled in Figure 3 can be seen near the center of Photo 3. The flume and gauge were installed in 1985 and passed all flow (except one event in 1988 which overtopped the concrete flume but was less than the elevation of the chart recorder) and sediment until 1996. According to Veenhuis (1998) "During the initial inspection on June 13, 1996, this flume was to be re-instrumented to monitor post-fire runoff, but on June 26, 1996 when the first and largest post-fire flood occurred (2,700 cfs), the flume was inundated with large boulders and debris. Thereafter the stream cut a channel on the right side of the flume wall and began down cutting and widening the channel to accommodate the larger flows." The new channel cross-section is also plotted in Figure 3 and can be seen to the right of the old flume in Photo 3.

Another significant aspect of the incision was the removal of the cobble and boulder armor from the streambed and exposure and incision into the underlying friable sandstone. This easily erodible bedrock is visible in Photo 2 as the white strata rising about 6 feet above the level of the stream. Incision into this unit might be providing a modern analog for processes leading to formation of terraces observed in many Pajarito Plateau Canyons (Reneau et al., 1996b). Because the intensities of both the Dome and La Mesa fires are believed to be unprecedented in the several-hundred-year long fire record on the Pajarito Plateau, it is possible that the resultant fluvial geomorphic effects are also unprecedented. While historic records show little in the way of large-magnitude floods outside of post-fire years, field evidence indicates catastrophic flooding has taken place in pre-historic times (Reneau et al., 1996b).

Stratigraphic relations and radiocarbon dating indicate that mid- to late-Holocene (within the last 5,000 years) sediments in many canyons recorded repeated episodes of alternating channel aggradation or stability and channel incision, with incision being dominant at an average rate of 4 mm/year (Reneau et al., 1996a). It is notable that there is abundant evidence for significantly larger floods on the floor of Capulin Canyon, including extensive boulder deposits commonly containing boulders much larger than those transported by recent floods (2,700 cfs). Their presence indicates the potential for significantly larger floods (Reneau, 1996). Depending on the interpretation of the base level of the channel bottom at the time of pre-historic flooding, flow reconstruction estimated a flood magnitude between 9,000 and 10,500 cfs. The cause of these earlier flood peaks is unknown (Veenhuis, 1998).

McCord (1996) examined flood-scars on trees and radiocarbon dates from sediments to reconstruct a record of past flood events on Frijoles Creek. The scar dates ranged in age from 1773 to 1985, with most of the scar dates falling in 1977 and 1978. McCord determined there have been at least four floods comparable to the 1978 flood (greater than 3,000 cfs) in the last two centuries, and at least seven floods as large as the flood of 1977 (653 cfs) during that time. Other than the 1977 scar, only the 1773 flood scar matches a major fire year in the local fire scar record. This suggests one of two possibilities: that fire intensity, rather than fire extensiveness, is the major factor leading to post-fire flooding; or, the occurrence of floods in Frijoles Canyon can be independent of fire (McCord, 1996).

Other potential sources of damaging floods are: rain on snow or other anomalous precipitation events, landslides, and debris flows. Cannon et al., (1998) determined debris-flow and landslide susceptibility in Capulin Canyon was low, but the potential for debris-flow was observed in two tributary canyons. Another potential scenario that could result in catastrophic flooding is an outwash event. As an example, the slope above Capulin Creek shown in Photo 2 has been destabilized by channel incision, and could become further destabilized as the friable sandstone is laterally eroded from the toe of this slope. If slumping occurred during a high-water event, the water could be dammed behind the slump and released as an outbreak event when the slump was overtopped, undermined, or circumvented. According to Allen (1989), landslides in the Jemez

Photo 1. Stream Channel Incision within Capulin Canyon.

Photo 2. Channel Incision and Potential Slope Destabilization in Capulin Canyon.

Photo 3. Old Peak-Flow Gauging Flume and Post-Flood Channel, Capulin Canyon.

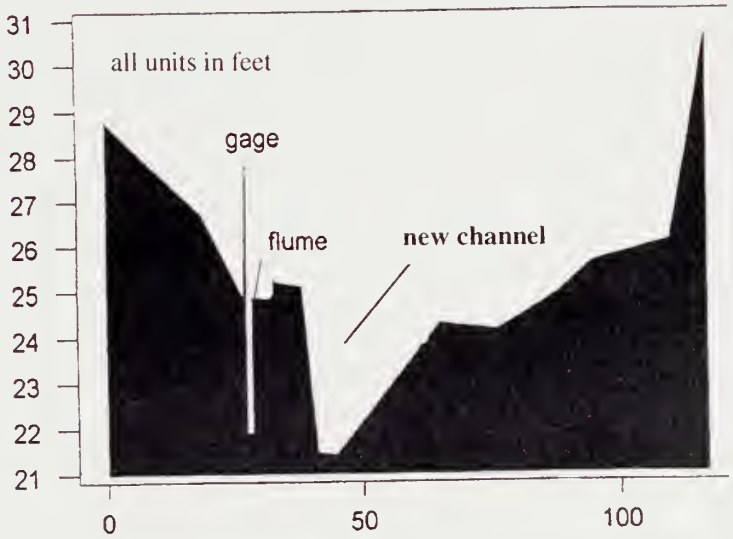

Figure 3. Post-Fire Cross-Section of Capulin Creek at Old Peak-Flow Gauge (Veenhuis, 1998).

Mountains occur mainly on steep slopes within canyons. In the Frijoles watershed, a landslide occurred below the lower falls in 1942, destroying about 150 yards of trail. At least three other notable rock-slides/landslides have occurred in the Frijoles watershed since that time (Allen, 1989).

Description of Recommended Project or Activity

In Bandelier's recently completed Water Resources Management Plan (Mott, 1999) it was recommended that a qualified geomorphologist should assess the potential for outbreak flooding in both Frijoles and Capulin Canyons. The study reach on Frijoles would include the section above the headquarters, while on Capulin it should focus on the reach above the Base Camp, which is required occupancy for NPS personnel during back-country patrols. Landslides and slumps in these canyon systems have been documented in the past. Recent destabilization of Capulin Canyon increases the likelihood of localized mass-movement. The principal question is whether the size of the slump or slide material is large enough relative to the streams transport power as to preclude a near instantaneous breach of the slide dam.

An additional recommendation was related to debris jams which might cause overbank flows. Flood hazard delineation procedures should be used to assess the potential for overbank flows to impact park structures. Bandelier should remove debris jams from the headquarters reach of Frijoles Creek only when they might cause flooding which could be a threat to life or property. At present, Bandelier has no criteria on which to base assessments of the danger associated with debris jams, or the best methods to use in removal. The WRMP recommended removal should be done with the least stream damage possible, and that some woody debris should remain as it provides the best habitat in this otherwise degraded reach of stream. These recommendations should be backed up by specific evaluations of the stream reach in question and the removal methods currently being used.

The specific technical assistance required would involve about two weeks work and related travel for both the USGS geomorphologist and NPS hydrologist assigned to the task. Specific questions to be answered include:

1. What is the potential for landslides within Bandelier's canyon systems, especially on Capulin Canyon where recent down cutting has occurred?
2. If a landslide did occur, what would be the "worst case scenario". Is the colluvial material of such a size and composition that it could be rapidly breached and release an outbreak flood?
3. Is overbank flooding a threat to Monument property or lives?
4. Are there overbank flow paths on floodplains that might route high water directly at the infrastructure?
5. At what level should natural logjams be considered a threat to Monument infrastructure and removed?
6. How should log jams be removed to minimize deviation from natural processes and minimize destruction of instream habitat?

It is proposed that a specialist from the USGS and the NPS cooperatively develop the response to this request because expertise from both agencies would have a synergistic effect. The USGS will have primary responsibility for data gathering, interpretation, and analysis, while the NPS will be the primary liaison with Bandelier's staff and management and develop final conclusions and recommendations. It is also possible that the reviewers recommend further studies, in which case they would be responsible for developing a project statement or appropriate funding vehicle.

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Project Statement
BAND-N-007.010

Last Update: 08/01/99 Priority: 0000
Initial Proposal: 08/01/99 Page Number: 0001

Title: Coordinate Interagency Native Fish Restoration Program at Bandelier National Monument

Funding Status: Funded: 0.00 Unfunded: 0.00
Technical Assistance Request

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number:

Summary

Bandelier contains several miles of perennial streams, the most notable is Frijoles Creek with 15 miles of flowing water with an average discharge of one cfs. It is open to debate whether or not Frijoles possessed a naturally occurring native fish population. Area fisheries biologists believe the regionally native Rio Grande cutthroat trout was endemic to Frijoles Creek, and this is supported by historic accounts. Past stocking with exotic salmonids would have eliminated native cutthroat, and Frijoles Creek's present fish population is made up exclusively of three species of exotic trout. National Park Service management policies require removal of exotic species where they are impacting native resources. These policies also require re-establishment of native species to their historic ranges. Frijoles Creek is within the native range of the Rio Grande cutthroat trout and is a favorable location for reintroduction because of the natural barriers (waterfalls), wilderness designation for much of the watershed, and relatively low fishing pressure.

While Monument managers recognize the need to eliminate exotics and restore the native aquatic community, they are concerned that conventional chemical extermination techniques will affect other stream organisms, and that unauthorized restocking by a disgruntled angler might jeopardize restoration efforts. A recently completed Water Resources Management Plan prepared for the National Monument identified new techniques being implemented at Great Smoky Mountains National Park which use multi-pass electro-shocking runs to remove exotic fish species from appropriate stream reaches and do not require introduction of toxins.

Both the New Mexico Department of Game and Fish and the U.S. Fish and Wildlife Service have performed Rio Grande Cutthroat restocking programs within northern New Mexico, and have the required expertise, brood stock, and hatchery facilities. Technical assistance is being requested from the Water Resources Division to provide the necessary expertise in coordinating a multi-agency, exotic species eradication project and possibly followed by a native species restoration project. Specifically, a fisheries biologist is required to be the liaison between Bandelier's managers and fisheries experts from other State and Federal agencies. Coordination will necessarily be a step-by-step process, beginning with organization of a meeting between Bandelier's managers and State and Federal representatives, moderated by the Water Resource Division fish expert. Initial focus will be given to developing and implementing the necessary investigations to determine if exotic trout eradication can be accomplished without use of toxicants. Bandelier lacks a water resource or fisheries person on their staff, and a trusted and knowledgeable voice from the National Park Service is required to integrate this important and possibly controversial restoration project.

Problem Statement

Background

Bandelier contains several perennial stream reaches and perennial streams typically harbor fish. However, no native fish species have ever been officially recorded for the streams within the boundaries of Bandelier National Monument (National Park Service, 1978; Platania, 1992; National Park Service, 1995a; Carter, 1997b). A number of native species (several extirpated) inhabited the Rio Grande and undoubtedly individuals utilized the perennial reach of Frijoles Creek below the lower falls. Other reports (Bandelier, 1890; Lummis, 1892; Willis, 1964; National Park Service, 1978) suggest Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis)* were once present in upper Frijoles Creek above the two lower falls. For example, both Lummis and Bandelier noted fish in Frijoles Creek in the late 19th century, although species identification was not part of their description. The historic range of the Rio Grande cutthroat trout is not definitely known although it likely encompassed all waters presently capable of supporting trout in the Rio Grande drainage (Stumpff and Cooper, 1996). Fisheries Biologists with the New Mexico Department of Game and Fish note the regional occurrence of this subspecies in streams similar to Frijoles Creek and believe Rio Grande cutthroat trout were native even above the barrier falls (National Park Service, 1978).

The Rio Grande cutthroat trout is New Mexico's state fish and was once widespread in the upper Rio Grande, Pecos, and Canadian River basins of northern New Mexico and south-central Colorado, possibly occurring as far south as Chihuahua, Mexico (Rinne, 1995). However, this subspecies of cutthroat has been in decline primarily as a result of hybridization and/or competition with exotic salmonids and habitat degradation. The current distribution of the Rio Grande cutthroat trout is estimated to be at 10 percent of its potential habitat (Stumpff and Cooper, 1996). The Rio Grande cutthroat is not federally

listed as a threatened or endangered species; however, action is required to prevent the further deterioration of its status (Olson, 1985).

If Rio Grande cutthroat were native to Bandelier, introduction of rainbow *(Salmo gairdneri)*, brown *(Salmo trutta)*, and brook trout *(Salvelinus fontinalis)* would have rapidly eliminated it because rainbow trout readily hybridize (introgression) with cutthroat trout, in general, and brown and brook trout appear to be better competitors (Behnke, 1992). Fish stocking by the New Mexico Department of Game and Fish commenced in 1912 and continued until 1955. Their records show 36,750 brook trout, 82,740 rainbow trout, and 368,404 cutthroat trout of Yellowstone origin (species name not listed) were planted in Frijoles Creek during this time. The nearby Alamo Creek received 13,000 brook trout, 4,000 rainbow trout, and 6,000 Yellowstone cutthroat between 1919 and 1931, while a third perennial stream, Capulin Creek, received 10,500 brook trout, 17,000 rainbow, and 1,500 Yellowstone cutthroat between 1922 and 1931. Undocumented introductions of brown trout have also occurred in these streams. Some of these nonnative trout species persist today with unknown impacts on the ecology of these streams and their rich aquatic invertebrate fauna (Allen, 1989a).

Platania (1992) employed electrofishing techniques to collect fish samples from four sites within Bandelier National Monument: 1) Frijoles Creek just above its confluence with the Rio Grande, 2) Frijoles Creek near Monument headquarters, 3) Frijoles Creek headwaters, and 4) Capulin Creek headwaters. One rainbow trout and two brook trout were collected at site 1, and 21 rainbow trout and 41 brown trout were collected from site 2. No fish were collected from sites 3 and 4, and three species of exotic trout represented the entire species diversity. Previous sampling information is unavailable for comparison to these results.

Only two fish species were collected from Frijoles Creek during USGS-National Ambient Water Quality Assessment (NAWQA) fish community sampling near Monument headquarters in 1994: 94 rainbow and 51 brook trout (Carter, 1997b). It is questionable that Carter found only brook trout and Platania found only brown trout associated with the rainbow trout in the headquarters reach of Frijoles. Either there was a dramatic shift in fish populations during the two-year interval separating their studies, or one of the authors mistakenly identified their catch. Fletcher (1990) while collecting fish samples to be analyzed for DDT contamination, found only brown and rainbow trout in Frijoles, and collected at least one brown trout from Capulin.

Of the four sites sampled, Platania (1992) determined the most productive stream reach was near the Bandelier National Monument headquarters. The density of rainbow and brown trout in this reach was fairly high with sizes ranging from 2 to 10 inches and it is utilized to a limited extent by anglers (National Park Service, 1978). Two waterfalls on the lower Frijoles Creek appear to prevent the occurrence of the Rio Grande sucker *(Pantosteus plebeius)* or other regional natives in Frijoles.

Discussion

Bandelier's complement of fish species appears to consist of three exotic, yet naturalized, trout species. Historical accounts, the physical setting, and regional fish distribution patterns have lead area fisheries biologists to conclude that Rio Grande cutthroat trout were once native to the Monument's perennial streams, specifically Frijoles Creek. However, definitive proof of Rio Grande cutthroat trout in the Monument is not available and probably never will be, mainly because cutthroat trout would have been extirpated by stocking of exotic trout early in the 20th century.

Primack (1993) pointed out that whereas patterns of evolution have proceeded as a result of geographic isolation, humans have radically altered this pattern by transporting species throughout the world. Any introduced species that survives the transfer necessarily affects the receiving ecosystem. Courtenay (1993) summarized that every introduction will result in impacts to the native biota, which range from almost nil to major, including extinction, with time. Nonnative species can affect native species through a number of mechanisms including hybridization, competition, predation, pathogen transfer, and habitat alteration.

Proposals dating back at least to 1961 called for the (re) introduction of Rio Grande cutthroat in Frijoles Creek above the falls, the earliest of these originated from National Park Service fisheries personnel (NPS, 1978). Frijoles Creek is attractive for the (re) introduction program because of the natural barriers, wilderness designation, relatively low fishing pressure, and absence of cattle grazing, among others. New Mexico Department of Game and Fish has successfully re-introduced this species in at least 45 other locations (Rinne, 1995).

Bandelier's management appeared willing to pursue the cutthroat reintroduction program in the late 1970s (NPS, 1978). Current managers note reintroduction requires tampering with the entire Frijoles Creek ecosystem because some means of eradicating the existing exotic species is required. They are specifically concerned with chemical extermination and its affect on other aquatic organisms, such as benthic macroinvertebrates. They also fear that with the easy access to this stream, unauthorized private restocking of exotic trout would again eliminate the native cutthroats. However, it is important to realize the exotic trout are tampering with the natural ecosystem (aquatic macroinvertebrates) as well.

Management Policies of the National Park Service (1988) state that "In natural, cultural, and park development zones, fisheries management will seek to preserve or restore natural aquatic habitats and the natural abundance and distribution of native species, including fish, together with the associated terrestrial habitats and species...Artificial stocking of native fish will be employed in natural areas only to reestablish native species in their historic ranges". Relative to exotic species NPS policy states "Management of populations of exotic plant and animal species, up to and including eradication, will be undertaken wherever such species threaten park resources." It further states "Examples of

threatening situations include: interfering with natural processes and the perpetuation of natural features or native species, especially those that are endangered, threatened, or otherwise unique."

Bandelier management used the above and related policy guidelines to remove feral cattle and burros from the Monument. A comparison can be made between the aquatic and terrestrial environs using feral ungulate eradication as an analog. However, the damage done by the exotic trout to Bandelier's aquatic ecosystems is much more comprehensive, and negates any possibility of native fish reintroduction.

Description of Recommended Project or Activity

Bandelier should evaluate the potential of using electroshocking and other alternative eradication techniques to remove exotic trout from its streams, with technical assistance and guidance provided by Water Resource Division fisheries staff, or a park based expert working through the affiliates program. As an example, personnel at Great Smoky Mountains National Park have had documented success eradicating exotic trout species from selected stream reaches using multi-pass electroshocking (Kulp, pers.comm., Great Smoky Mountains National Park, 1998; Larson et. al., 1986).

A recent agreement between the Jicarilla Apache tribe, New Mexico Department of Game and Fish, and the U.S. Fish and Wildlife Service to reestablish this subspecies on tribal lands in the nearby Rio Chama basin indicates partnerships are still being implemented to pursue this goal (U.S. Department of Interior, 1998). Additionally, further investigations (e.g. examination of fish bones from archeological digs) could be conducted to determine the probability that Rio Grande cutthroat once swam Bandelier's waters. Replacement of exotic species with regional natives is a preferred course of action based on NPS management policies.

As part of the development of a Water Resources Management Plan for Bandelier, New Mexico Department of Game and Fish was contacted and their interest in working with the Monument of this project was preliminary assessed. Medley (pers. comm., New Mexico Department of Game and Fish, 1999) stated that the Department also has experience using multi-shocking techniques to remove exotic fish. Medley further stated that the Department would be very interested in working with the NPS to assess Frijoles Creek as a candidate stream for Rio Grande cutthroat reintroduction. Furthermore, the Department could assist in relocating shocked fish from Frijoles Creek into other streams where an exotic fish community is already established and native fish restoration is not practical.

Environmental assessments provide a mechanism to plan a project and to select the best alternative that will accomplish the goals and objectives. A comparison of alternative actions and the potential impacts are vital to the success of the project, and such planning should be axiomatic in any restoration program (Wiley and Wydoski, 1993). An environmental assessment for the restoration of Rio Grande cutthroat trout to Frijoles will

not only evaluate the relative impacts of the program (i.e. action vs. no action), but also evaluate various techniques to accomplish the restoration (i.e. chemical vs. mechanical vs. integrated). The environmental assessment should be a cooperative effort between the National Park Service, New Mexico Department of Game and Fish, and U.S. Fish and Wildlife Service. This technical assistance requests clearly justifies the need for an NPS fisheries experts to coordinate preliminary assessments and develop a mutually acceptable course of action based on these assessments and multi-agency interaction.

Specifically, a fisheries biologist is required to be the liaison between Bandelier's managers and fisheries experts from other State and Federal agencies. Coordination will necessarily be a step-by-step process, beginning with organization of a meeting between Bandelier's managers and State and Federal representatives, moderated by the Water Resource Division fisheries personnel. Initial focus will be given to developing and implementing the necessary investigations to determine if exotic trout eradication can be accomplished without use of toxicants. Bandelier lacks a water resource or fisheries person on their staff, and a trusted and knowledgeable voice from the National Park Service is required to integrate this important, policy mandated, and possibly controversial restoration project.

Contacts with the New Mexico Department of Game and Fish include:

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Peter Wilkinson, Fisheries Division Supervisor, (505) 827-7905

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Project Statement
BAND-N-007.011

Last Update: 08/01/99 Priority: 0000
Initial Proposal: 08/01/99 Page Number: 0001

Title: Conduct Stream Flow Gain and Loss Studies to Assess Potential Ground Water Contamination

Funding Status: Funded: 00.0 Unfunded: 33.8 and including Technical Assistance Request

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number:

Summary

Bandelier National Monument contains significant water resources including springs, streams, riparian areas and ground water. Along streams and within riparian areas, ground and surface waters are interconnected. Of special significance is Frijoles Creek, the only stream in the Monument, and one of only a few in the middle Rio Grande basin, that maintains perennial flow throughout its entire length. As another example of Frijoles significance, a USGS assessment which looked at the entire Rio Grande basin determined Frijoles Creek was the least disturbed of any study site (Levings et al., 1998).

Adjacent to the northern boundary of the Frijoles Creek watershed is Los Alamos National Laboratory (LANL). Radioactive and hazardous wastes have been generated and disposed at this Department of Energy facility since its inception in 1943. More than 2,000 potentially contaminated sites or solid waste management units were recognized by LANL in 1995 (Stone, 1996). In 1979, it was estimated that about three million pounds of solid radioactive waste were buried in trenches and shafts dotting LANL's mesas (Stevens, 1982). Abrahams (1963) stated that radioactive wastes from Los Alamos have been released into the air, onto the surface, and into the subsurface in unknown quantities.

Based on early geohydrologic models, Laboratory managers overestimated the ability of the Pajarito Plateau's volcanic strata to attenuate movement of hazardous materials. Reneau (1998) reports that geologic and geohydrologic knowledge of Bandelier's subsurface is changing rapidly as a result of the implementation of LANL's *Hydrogeologic Workplan,* and that "New wells have demonstrated contamination deeper

and in different places than previously recognized." Newly developed ground water flow path maps show perched groundwater beneath LANL flows south, toward Bandelier. The elevation of the potentiometric surface, and the fact that Frijoles Creek gains flow along some intervals due to ground water input, indicates ground water moving from LANL could be recharging Frijoles Creek (Purtymun and Adams, 1980). Detection of contaminants derived from high explosives within Frijoles Creek further confirms this possibility (Gallaher, 1998).

This proposal seeks funding for monthly seepage runs within Bandelier National Monument throughout a range of flow conditions. A seepage run (sometimes referred to as a gain and loss study) is a series of meticulously accurate discharge measurements and associated readings taken at close intervals along a stream. Seepage runs are used to locate gaining and losing stream reaches and quantify ground water inputs or surface water infiltration. Discharge measurements will be conducted through a range of base flow conditions along the entire length of Frijoles Creek, and perennial portions of the adjacent Alamo Creek. Alamo Creek is included because staff at LANL has indicated that it could also be a resurgence point for ground water recharged at the Laboratory. Alamo Creek is also important to assess because it would show if gaining reaches of Frijoles were spatially associated with gaining reaches on Alamo. The purpose of quantifying and characterizing ground and surface water interactions is to adequately assess potential for contaminated ground water to be moving into Bandelier's surface streams. Bandelier's managers will use the results to evaluate existing water-resource management strategies being developed within the park and on the adjacent LANL, and develop appropriate objectives for water-resource protection.

Problem Statement

INTRODUCTION

Knowledge of the interaction between groundwater and surface water in a drainage basin increases the understanding of the hydrologic system and aids in the management of water resources (Freiwald, 1987). Flow measurements made over a short period of time and under uniform hydrologic conditions at numerous sites along a stream are among the best sources of obtaining this knowledge. These data help identify stream reaches where gains from groundwater discharge and losses from groundwater recharge occur. In addition, information about the magnitude and distribution of low flows and anomalies within the stream basin related to hydrogeology and biogeochemistry can be examined if these studies are repeated through a variety of seasons and base-flow conditions.

The exchange of water between a stream and aquifer depends on the stage of the stream in relation to the water level in the aquifer (Stringfield and LeGrand, 1969). Streams loose flow to the ground-water system when the stream stage is above the water table. Conversely, aquifers discharge water to the stream where the water table is above the stream stage. In addition to natural ground water contributions, ground-water contaminants, if in occurrence, also have the potential to discharge into the surface water and will have profound affects during base-flow conditions. Identifying stream reaches

that contribute to or receive groundwater will provide vital information related to the interconnection of aquifers and surface streams.

Purtymun and Adams (1980) conducted limited sampling along Frijoles Creek and noted that stream flow increased from the springs near its head to the crossing of the Pajarito fault line. They attributed this increased flow to return flow from thinning alluvium, seepage from colluvium at the base of the canyon walls, and movement of water through brecciated zones associated with the faults. Surface flow appeared to decrease from the fault line to the confluence with the Rio Grande. They also reported intermittent reaches of Frijoles Creek during some summers. This project will investigate gain and loss along Frijoles and Alamo Creeks at monthly intervals in a much more temporally expansive and spatially detailed manner, so that results can be correlated with ongoing geohydrologic investigations at LANL.

BACKGROUND

Bandelier National Monument was established in 1916 to preserve what remains of the area's once thriving Ancestral Puebloan culture. It was the Monument's springs, streams, and riparian zones which allowed these ancient agrarians to flourish in an otherwise harsh landscape. The occurrence of water over a wide range of elevations and microclimates continues to support Bandelier's diverse assemblage of plants and animals, and provides the visitor from today's world a different manner of sustenance.

Water is often a significant resource in units of the National Park Service, either through support of natural systems, administrative use, or visitor enjoyment. At Bandelier, over 400,000 visitors per year fish, wade, camp and hike in and along Bandelier's streams and riparian corridors. While water resources are central to the Monument's interpretive theme, they are even more important as vestiges of a resource in decline within America's desert southwest, where high quality streams and riparian zones are becoming increasingly scarce.

Bandelier's most intensely developed neighbor is Los Alamos National Laboratory that encompasses 27,520 acres to the north. LANL has been involved in numerous large-scale research and development projects, including nuclear reactors, weapons, and specialized high explosives, since its inception in 1943. LANL's lands are almost exclusively outside the Monument's surface watersheds such that contamination of the Monument's water resources from LANL practices initially seemed unlikely. However, recent and ongoing investigations have and continue to document extensive ground water contamination in all three ground water zones below LANL. Of particular concern to Bandelier is contamination of perched ground water. Recent hydro-stratigraphic mapping and interpretation indicates perched water could be migrating toward Bandelier and recharging Frijoles or Alamo Canyons within the Monument. Perched water and associated contaminants could also be migrating through the Pajarito Fault zone.

Ground water beneath the Pajarito Plateau occurs in three zones: the shallow alluvium of canyons; perched on relatively impermeable strata; and in the main aquifer (Los Alamos

National Laboratory, 1995). Almost everything that is known about the area's ground water comes from investigations conducted by or for Los Alamos National Laboratory. Despite the millions of dollars and years spent sampling, modeling, and quantifying subsurface waters, these systems remain a conundrum. One thing appears certain, early interpretations of the area's hydrolgeology overestimated the Pajarito Plateau's ability to trap or attenuate hazardous materials (Purtymun and Cooper, 1969; Purtymun and Johansen, 1974; Purtymun and Adams, 1980; Purtymun, 1984; Purtymun et. al., 1989).

Ground water sampling summarized by the U.S. Department of Energy (1998) documented a myriad of contaminants in alluvial and perched ground water, many of which exceed EPA or New Mexico water quality criteria. Even in the main aquifer, tritium, plutonium-239 and -240, americium-241, and strontium-90 have been detected, as well as organic compounds and nitrates. Because these products were originally discharged to canyon streams or buried on mesa tops, as opposed to injected directly to ground water bodies, their presence in monitoring and production wells confirms vertical migration through underlying deposits. Mechanisms allowing this vertical migration involve fracture, fault, joint, surge bed and other permeable unit through-flow under canyons or mesas during the wetter seasons (Rogers et al., 1996a; Turin and Rosenberg, 1996).

Environmental surveillance conducted by Los Alamos National Laboratory in 1990 (LANL, 1992) included radiochemical analysis of sediments from Frijoles at Bandelier headquarters. The highest total uranium concentration (5.2 µg/g) and gross gamma counts (4.7 counts/min/g) of 36 sites sampled were reported from Frijoles Creek. A detection of contaminants derived from high explosives was reported in Frijoles Creek at low levels by LANL researchers in 1996 (Gallaher, 1998).

Zones of perched water exist beneath most, if not all, of the wetter canyons of the Pajarito Plateau. These perched bodies are recharged mainly by intermittent and perennial stream flow loss to alluvial sediments and, ultimately, underlying volcanics (Los Alamos National Laboratory, 1995; Los Alamos National Laboratory, 1998b). Dale (1996) reports that historically, LANL disposed of a portion of its liquid radioactive waste by discharging to canyons, underground storage tanks, and absorption beds.

Examples of shallow ground water contamination includes tritium in four, intermediate-depth, perched ground water locations in lower Los Alamos Canyon. Well LADP-3 is down gradient from the Omega Reactor, which was discovered in 1993 to have been leaking tritiated cooling water for some time (Rogers et al., 1996b). Analysis of water from Ancho Spring near the Monument indicated the presence of numerous constituents found in high explosives and trace levels of depleted uranium. Bore holes drilled through or next to absorption beds or angled beneath waste disposal shafts encountered primarily Pu, AM, 137-Cs, 90-Sr (Los Alamos National Laboratory, 1998b).

It is important to realize that while there are no streams or drainages which flow directly from LANL onto Bandelier, there are also no streams which flow from LANL to the Rio Grande under base flow conditions (Purtymun and others, 1980). Ultimately, all streams

within LANL are losing or intermittent streams. This is significant given that total effluent releases from sewage and other treatment plants in and near the Laboratory are over three times greater than incoming stream-flow onto the Laboratory (LANL, 1998b). Over the past five decades, this surface infiltration has recharged subsurface waters that have thereby accumulated contaminants. Ground water flow rates are slow beneath the Pajarito Plateau, and contaminant plumes, if present, may not have migrated far enough to intercept Frijoles Creek yet.

Stone (1996) focused on ground water issues and presented ten unanswered questions related to the complex nature of the many zones of water beneath the Pajarito Plateau and its canyons:

1. How many perched water zones are there?
2. How deep is the ground water?
3. What is the lateral extent of the perched water zones?
4. Is there recharge through the tuff?
5. What is the ground water flow direction around the well fields?
6. Why are all the springs in the White Rock Canyon attributed to the main aquifer?
7. Where does perched ground water below the Pajarito Plateau go?
8. What is the water budget of the Pajarito Plateau?
9. What is the background hydrochemistry for each of the saturated zones?
10. What is the inventory of radionuclides in the canyons?

In response to documented ground water contamination and the need to answer basic ground water questions, LANL has developed a comprehensive *Hydrogeologic Workplan* (LANL, 1998b). This document describes activities to be performed by Los Alamos National Laboratory to characterize the hydrogeologic setting beneath the laboratory, and enhance the laboratory's groundwater monitoring program. The planning was completed with close oversight from the New Mexico Environmental Department that stated four issues and questions that the Department considered unresolved:

1. Individual zones of saturation beneath the Laboratory have not been adequately delineated, and the "hydraulic interconnection" between these is not understood;
2. The recharge area(s) for the regional aquifer and intermediate perched zones have not been identified, and the effect of fracture-fault zones on recharge is unknown;
3. The ground-water flow direction(s) of the regional aquifer and intermediate perched zones, as influenced by pumping of production wells are unknown; and,
4. Aquifer characteristics cannot be determined without additional monitoring wells installed within the specific intervals of the various aquifers beneath the facility.

These questions are also pertinent to Bandelier because of the potential for perched water zones recharged below LANL to contribute flow to Frijoles Creek or possibly Alamo Canyon (Reneau, 1998). Reneau also reports that geologic and geohydrologic knowledge of Bandelier's subsurface is changing rapidly as a result of the implementation of the *Hydrogeologic Workplan* and that "New wells have demonstrated contamination deeper and in different places than previously recognized."

One potential transport path for these contaminants is shown in the accompanying figure. This structural contour map shows the elevation of the base of the Bandelier Tuff, which is recognized as a perching boundary due to the relatively impermeable nature of the underlying basalt. The map also shows the inferred flow direction of perched water within the basal Guaje Pumice Bed - south toward Bandelier National Monument. Because the lowest structural contour line is 6,100 feet and an outcrop of basalt in the Frijoles channel was observed near the Frijoles gauge at an elevation of approximately 6,040 feet, water perched on the basalt could add recharge to Frijoles Creek. Even without the existence of the trough, alluvial recharge of perched water zones below Ancho or other LANL canyons to the North, could provide positive flow and contaminants to Frijoles Creek.

Another potential ground water transport path from LANL to Bandelier is through the Pajarito Fault zone. Purtymun and Adams (1980) measured increased flow in Frijoles Creek as it passed through this fault zone. The source of this water input is unknown but could include recharge from western areas of LANL. Fractures within basalt can also lead to the development of secondary porosity, increasing hydrologic conductivity and contaminant transport. In 1996, low levels of constituents found in high explosives were detected in Frijoles Creek at Monument Headquarters (Los Alamos National Laboratory, 1998a).

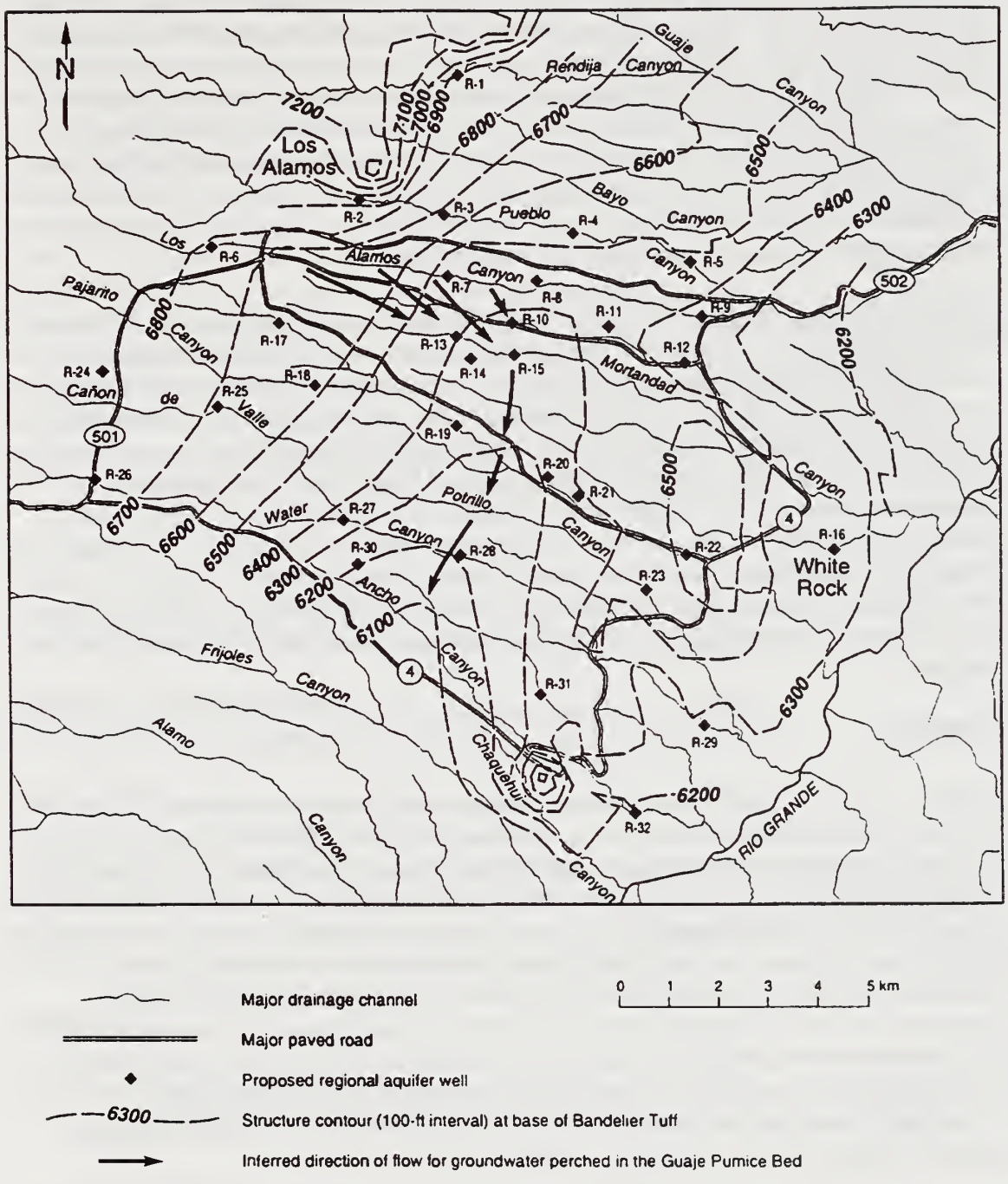

Figure 1. Inferred Direction of Perched Ground Water Flow Below Los Alamos National Laboratory and Locations of Proposed Regional Aquifer Monitoring Wells (LANL, 1998b).

Description of Recommended Project or Activity

A series of detailed seepage runs should be performed on the entire length of Frijoles and Alamo creeks. The main purpose of this project is to identify spatial locations of ground

water input to Frijoles and Alamo Creeks as related to issues associated with LANL as discussed previously. Other purposes include evaluating the impacts of the State's road salting operations on surface and ground water resources, and determining whether the reach of Frijoles Creek at the Monument headquarters is a gaining or losing segment, as related to potential sewage leakage concerns. Objectives include: 1) identifying the spatial locations of ground-water upwelling and stream-water downwelling, 2) characterizing how gaining and losing reaches vary from May until October and therefore throughout a range of seasonal and base flow conditions; and 3) measuring conductance and temperature throughout the length of these streams.

The above studies should be conducted during various times of the year and differing levels of base flow. For example, measurements taken near the end of the spring snowmelt could reveal areas receiving road salt runoff and a high degree of recharge from higher elevations, such as in the vicinity of the Pajarito Fault zone. Measurements taken in times of lowest base-flow, when ground water losses and inputs would be at their relative highest, would best reveal areas influenced by perched ground water. Measurements during lowest base flow would also help determine if Frijoles Creek is gaining or losing flow in the vicinity of the headquarters, and if gaining, could be bringing in contaminated water from leaking sewage infrastructure. Finally, a seepage run conducted when the plant community is dormant and evaporation is relatively low (late fall) would show the relative influence of evapotranspiration on canyon water budgets.

Approach

Synoptic discharge measurements taken throughout the lengths of Frijoles and Alamo Canyons will be conducted once per month from May until October throughout a range of base flow conditions and seasonal influences. Ground water influx is expected to reach its highest ratio during summer when stream discharges are at their lowest and the contribution from surface runoff is at its minimum. A seasonal technician will be hired to perform the field work and will be trained by a hydrologist from the NPS Water Resources Division at the start of each field season. The NPS hydrologist will be providing assistance through a parallel technical assistance request. The duties of the NPS hydrologist will include: 1) training the technician in proper field procedures for data collection; 2) working with the technician on the first run of each season; 3) developing base maps and the use of a GPU for locations; and, 4) preparing a report summarizing the results of the project upon completion.

Discharge, water temperature and specific conductance will be measured approximately every 500 meters. Temperature and discharge will be screened at 100 meter intervals so that discharge measurements can be made anywhere there is a significant change in water temperature or specific conductance (fluxes in these parameters would indicate ground water insurgence). Discharge, temperature, and specific conductance will also be measured in any confluencing tributaries or springs, or wherever incoming flow is visible. Discharge and other measurements will be made using state of the art meters and following accepted EPA or USGS protocols. Because it is not anticipated that Bandelier

will have a need for these meters after the study is complete, they will be returned to the Water Resources Division for use on other NPS projects. Spatial location of discharge recording sites and other important features will be identified using GPS instrumentation already available at Bandelier. Discharge data will be compiled throughout the downstream gradient of these streams to compare successive downstream discharge measurements in order to determine if individual stream reaches were gaining or losing flow. Maps will be prepared identifying spatial locations of streamflow gain and loss.

Once the field measurements are completed, a hydrologist with the Water Resources Division will be responsible for condensing all data into a final report. This report will also review the latest developments from LANL's *Geohydrologic Workplan* and integrate the findings of these two studies to the extent possible. The report will describe the project, the methods of data collection, data analysis, and streamflow gain and loss determinations. This report will be used by NPS to evaluate existing water-resource management strategies being developed within the park and on the adjacent LANL, and develop more appropriate objectives for water-resource protection.

Budget

Seasonal Technician (GS7 for 6 months and 2 years)..... $30,000

Flow meter, Marsh-McBirney..... $ 3,000
Wading Rod to accompany flow meter.....$ 500

Conductivity and temp meter (Orion suggested) .....$ 300

Possible sources of cost-share and technical assistance include LANL, NMDEQ, and BAND kicking in overhead, GPU and GIS, and supervision and maybe the temperature and conductivity meters from previous work. Also possible to have LANL cover al costs and perform all work since it is responsible under CERCLA.

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Project Statement
BAND-N-007.012

Last Update: 08/01/99 Priority: 0000
Initial Proposal: 08/01/99 Page Number: 0001

Title: Assist with Nomination of Outstanding National Resource Waters At Bandelier National Monument

Funding Status: Funded: 0.00 Unfunded: 0.00
Technical Assistance Request

Servicewide issues: N11 (WATER QUALITY)
N20 (BASELINE DATA)

Cultural Resource Type:
N-RMAP Program Codes: Q00 (Water Resources Management)
Q01 (Water Resources Management)

10-238 Package Number:

Summary

Bandelier National Monument contains many miles of perennial streams, most of which are in a wilderness setting. The quality of these streams and their corridors, the preservation of natural flows within them, and their location within the desert southwest, combine to make these streams highly significant water resources. The State of New Mexico has recently adopted a procedure whereby streams may be nominated for Outstanding National Resource Waters. Monument managers need assistance in developing the nomination package and determining which stream reaches are appropriate under New Mexico's interpretation of this component of the Clean Water Act. Other NPS administered streams in New Mexico could be nominated as part of the same package if determined applicable.

Problem Statement

Rosenlieb (1998) has been reviewing and commenting on revised surface water standards for the State of New Mexico on behalf of the National Park Service. In his initial review, Rosenlieb presented comments to the New Mexico Environmental Office and the U.S. Environmental Protection Agency concerning the lack of a nominating process for Outstanding National Resource Waters within New Mexico. Outstanding National Resource Waters (ONRW) can be an important designation for in-park waters because it provides the highest level of water quality protection within most state hierarchies. Many states link an antidegradation policy to ONRW designation that mandates no reduction of existing water quality. This is especially important where upstream, non-park, water quality impairment is likely or ongoing. Outstanding National

Resource Water designation can also place additional compliance responsibilities on park management. For example, the physical impairment, sediment loading, and embeddedness within Rito de los Frijoles at Monument headquarters could well be viewed as a violation of the antidegradation clause under ONRW standards.

The process for nominating ONRW waterbodies has been identified by NMED and includes the following steps (Rosenlieb, 1998):

1. A map of the surface waters of the state, including the location and proposed upstream and downstream boundaries;
2. A written statement in support of the nomination, including specific reference to the applicable criteria for ONRW;
3. Supporting evidence demonstrating that one or more of the applicable ONRW criteria listed in Section 1101.c of the Part has been met;
4. Water quality data to establish a baseline for the proposed ONRW;
5. A discussion of activities that might contribute to the reduction of water quality in the proposed ONRW; and,
6. Any additional evidence to substantiate such a designation.

The NMED Commission and possibly the New Mexico legislature still must approve the proposed nomination procedure. Therefore, final procedures are not expected to be put forth any sooner than late spring of 1999 (Rosenlieb, 1998).

Description of Recommended Project or Activity

In Bandelier's recently completed Water Resources Management Plan (Mott, 1999), it was recommended that managers pursue ONRW designation for Alamo and Capulin Creeks, at a minimum. This would help protect these streams from upstream water quality impairment and lend additional weight to Bandelier's argument that fire management efforts in the watersheds should be implemented to protect these streams. Table 1 gives a more complete listing of stream information relative to Bandelier. Managers have expressed an interest in determining which other streams or stream reaches might qualify for ONRW status once the details of the nomination criteria are understood. The ONRW nomination package could be forwarded to the State along with nominations from other parks in New Mexico.

Table 1. Stream Information for Bandelier National Monument's Canyons (Compiled from Purtymun and Adams, 1980).

Name	*Location of Headwaters*	*Drainage Area (mi.^{2})*	*Perennial Reaches**	*Average Gradient* (ft/mi.)*
Chaquehui Canyon	Pajarito Plateau	1.8	M	all = 475
Frijoles Canyon	Sierre de los Valles	19.8	U,M,L	U=397;M,L=158
Lummis Canyon	Pajarito Plateau	7.6	None	all = 211
Alamo Canyon	Sierre de los Valles	19.1	U,M,L_p	U=397;M,L=211
Capulin Canyon	San Miguel Mountains	19.6	U,M,L_p	U=317;M,L=211
Medio Canyon	San Miguel Mountains	6.6	U	U=686;M,L=211
Sanchez Canyon	San Miguel Mountains	7.7	M	U=422;M,L=211

* U = Upper, M = Middle, L = Lower, L_p = Portion of Lower

Some stream reaches may not qualify for ONRW status or are characterized by specific management concerns related to the designation. For example, ongoing impacts within the upper (USFS lands) portion of the watershed, or on specific stream reaches degraded by visitor traffic, may not qualify. Also, a recommendation regarding Frijoles Creek will require additional management consideration. ONRW designation could benefit Frijoles through the following: 1) New Mexico Environmental Department might assess potential Los Alamos National Laboratory (LANL) contaminant migration more seriously and might get more directly involved with monitoring and protecting Frijoles; 2) LANL would have additional justification for characterizing and monitoring potential ground water and contaminant migration into Frijoles Creek; and, 3) the designation could help justify funding and support for sewage system upgrades, efforts to restore the degraded headquarters stream reach, watershed restoration, further cooperative efforts with the state to assess the impacts of non-native species, and the determination of appropriate action with regard to DDT levels in fish. This designation could also put significant external pressure on the park to address habitat damage near the picnic area. Managers may want to rectify this situation before proceeding with this nomination. The NPS would also not be allowed to discharge treated sewage to ONRW streams. It is unknown how storm water runoff from the headquarters parking, maintenance, and office facilities would be viewed under this designation within New Mexico.

It is anticipated that three weeks would be required to research the designation process, discuss alternatives with Monument staff, and initiate work tasks required in the nomination package. An additional trip may also be required to formally assess the various streams in comparison to the requirements of the State's nomination program. Finally, another week would be required to put a nomination package together and submit it to the State. Bandelier staff could assist with development of maps and other items, while other members of the Water Resources Division could develop water quality summaries based on the Inventorying and Monitoring report recently completed (National Park Service, 1997).

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NPS D-79, September 1999

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